USCG-M-1-94.1
DOT-VNTSC-CG-94-5.1

Passenger Vessel Damage Stability Study for 1990 SOLAS Amendments
Volume I

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Final Report
September 1994

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U.S. Department
of Transportation
**United States
Coast Guard**

Office of Marine Safety, Security,
and Environmental Protection
Washington, DC 20593

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1994	Final Report 1994

4. TITLE AND SUBTITLE
Passenger Vessel Damage Stability Study for 1990 SOLAS Amendments - Volume I

5. FUNDING NUMBERS
B4039
CG486

6. AUTHOR(S)
Michael G. Dyer

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Department of Transportation
John A. Volpe National Transportation Systems Center
55 Broadway
Cambridge, MA 02142

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-CG-94-5.1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Coast Guard Headquarters
Commandant G-MTH-3
2100 2nd Street, SW
Washington, DC 20593

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
USCG-M-1-94.1

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public through the National Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The application of new damage stability requirements in the 1990 Safety of Life at Sea (SOLAS) amendments to the United States domestic passenger fleet is investigated. The amendments specify new minimums for positive range, righting energy, and downflooding angle, maximum static heel angle, and residual righting arms in situations of applied heeling moments such as passenger crowding and wind loading. Twenty-one domestic passenger ships of recent design are analyzed for their ability to comply in damaged conditions as specified by the Coast Guard regulations. Design modifications required to bring about compliance for those vessels failing the requirements are briefly addressed. A comparison of ability to comply versus certain hydrostatic parameters is made, as well as a set of recommendations to the Coast Guard.

14. SUBJECT TERMS
Passenger vessels, damage stability, SOLAS

15. NUMBER OF PAGES
92

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

PREFACE

This report was prepared by the John A. Volpe National Transportation Systems Center, U.S. Department of Transportation Research and Special Programs Administration for the Naval Architecture Branch (G-MTH-3) of U.S. Coast Guard Headquarters. We are thankful for the patience and advice of G-MTH-3 staff, especially Ms. Pat Carrigan, Mr. Jaideep Sirkar, and Mr. Paul Cojeen.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2 = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2 = 0.09 square meter (m_2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (1)
1 pint (pt) = 0.47 liter (1)
1 quart (qt) = 0.96 liter (1)
1 gallon (gal) = 3.8 liters (1)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] ^oF = y ^oC

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yeards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliters (ml) = 0.03 fluid ounce (fl oz)
1 liter (1) = 2.1 pints (pt)
1 liter (1) = 1.06 quarts (qt)
1 liter (1) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] ^oC = x ^oF

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0		1		2			3		4			5		6		7			8		9			10	
CENTIMETERS	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

^oF	-40^o	-22^o	-4^o	14^o	32^o	50^o	68^o	86^o	104^o	122^o	140^o	158^o	176^o	194^o	212^o
^oC	-40^o	-30^o	-20^o	-10^o	0^o	10^o	20^o	30^o	40^o	50^o	60^o	70^o	80^o	90^o	100^o

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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APPENDICES

NOTE: Appendix B, "Hydrostatics and Damage Stability Results", is available separately upon request, in Volume 2 of this document.

FIGURES AND TABLES

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List of Tables (cont.)

ABBREVIATIONS AND SYMBOLS

AP	after perpendicular
B	maximum breadth
C_b	block coefficient
CFR	Code of Federal Regulations
FP	forward perpendicular
GG_1	shift of vertical center of gravity due to passenger movement
GZ	righting arm
GZ_{reqd}	righting arm specified by new regulation, minimum of 0.328' or GZ calculated to sustain design heeling moments
LT	long ton = 2240 lb.
MTWB	main transverse watertight bulkhead
PAX	# of passengers
SOLAS	International Convention for the Safety of Life at Sea, with amendments
VCG	vertical center of gravity
VCG_0	initial vertical center of gravity
VCG_1	vertical center of gravity compensated for shift in weight (passengers)
Δ_{intact}	intact displacement

EXECUTIVE SUMMARY

Twenty one domestic passenger ships of recent design were analyzed for their ability to comply with new damage stability requirements in the 1990 Safety of Life at Sea (SOLAS) amendments. The results include fifteen vessels studied in 1990 and six of the most recent designs, for which a 1993 study was completed. The new regulations incorporated in 46 CFR §171.080(e) greatly reduce the risks to passengers, compared to the pre-existing damage stability requirements. Design modifications required to bring about compliance for those vessels failing the requirements were briefly addressed.

The major findings were the following (detailed findings are presented in "Conclusions and Recommendations"):

- The designs studied were, for the most part, able to sustain the new requirements (see Table E.1). They greatly exceed, whether implicitly or by design, the minimal damage stability requirements of the pre-1992 CFR.
- The controlling criterion among the SOLAS amendments was, in every case, righting arm for passenger crowding heeling moment. Five vessels, four of which were 91 feet in length or less, failed this requirement. The failure of the 192' casino boat was due to inconsistent bulkhead spacing resulting in a long forward compartment.
- In cases where vessels satisfy the passenger heel righting arm requirement, resulting heel angles are often quite large. Neither SOLAS nor the Coast Guard regulation limit the angle.
- Only one vessel, the 80' long paddle wheeler, failed any requirements other than passenger crowding heel, those being positive range and righting energy.
- Beamy shallow forms and low displacements associated with high passenger capacities were disadvantageous relative to passenger crowding moments. Small passenger boats with low breadth to depth and high freeboard to depth ratios fared well.
- 15° downflooding protection range was not directly addressed due to software and vessel documentation limitations, but will probably impact some designs for protected waters. Various extents of access and venting modifications may be needed to satisfy this provision.
- A step-wise approach to downflooding protection reflecting service areas could preserve the intent of the new regulations while sensibly accounting for operational and design factors.
- More specificity is recommended for minimum access/egress requirements for offloading from either side of the boat and for the modeling of passenger crowding loads. It was found that the CFR, supplemented by Coast Guard letter guidance, lacks specificity and would allow wide latitude to both the designer and the inspection authority. In some cases herein, crowding scenarios resulting in compliance and failure were devised.
- The CFR does not account for grounding damage scenarios and therefore drives some designs to unduly emphasize B/5 collision damages only, e.g. extremely long centerline compartments on the 274' paddle wheeler flanked by subdivided wing spaces.

Table E.1
Compliance Summary

VESSEL (design year)	15° pos. range	2.82 ft-degree righting energy	Min. GZ passenger crowding	Min. GZ boat launch	Min. GZ wind loading	Max. angle static heel <7°
FISHING/SHUTTLE						
80' fishing boat (1993)*	yes	yes	no	NA	yes	yes
59' fishing boat (1985)	yes	yes	no	NA	yes	yes
80' shuttle boat (1993)	yes	yes	yes	NA	yes	yes
DINNER/EXCURSION BOATS						
105' dinner boat (1988)	yes	yes	yes	NA	yes	yes
106' dinner boat (1993)	yes	yes	yes	NA	yes	yes
200' excursion boat (1993)	yes	yes	yes	NA	yes	yes
183' dinner boat (1988)	yes	yes	yes	NA	yes	yes
192' excursion boat (1986)	yes	yes	yes	NA	yes	yes
CASINO BOATS/PADDLE WHEELERS						
80' paddle wheeler (1986)	no	no	no	NA	yes	yes
198' casino boat (1993)	yes	yes	no	NA	yes	yes
228' casino boat (1993)	yes	yes	yes	NA	yes	yes
274' paddle wheeler	yes	yes	yes	NA	yes	yes

Table E.1 continues on next page

Table E.1 (cont.)
Compliance Summary

VESSEL	15° pos. range	2.82 ft-degree righting energy	Min. GZ passenger crowding	Min. GZ boat launch	Min. GZ wind loading	Max. angle static heel <7°
CONVERTED CREW BOATS						
91' crew boat A (1986)	yes	yes	yes	NA	yes	yes
91' crew boat B (1986)	yes	yes	no	NA	yes	yes
99' crew boat (1986)	yes	yes	yes	NA	yes	yes
102' crew boat (19870)	yes	yes	yes	NA	yes	yes
122' crew boat (1987)	yes	yes	no	NA	yes	no
PASSENGER CRUISE VESSEL						
180' cruise boat	yes	yes	yes	yes	yes	yes
FERRIES						
84' ferry (1988)	yes	yes	yes	NA	yes	yes
175' ferry (1982)	yes	yes	yes	NA	yes	yes
192' ferry (Sub chapter H)	yes	yes	yes	NA	yes	yes

* 80' fishing boat calculations were from "concept" drawings, using notional VCG of 9.00'

NOTE: Results only for collision cases described in CFR are considered for this Table. Cases of groundings with extensive transverse damage conducted in the study, and not specified by CFR, are not included.

Table E.1
Compliance Summary

VESSEL (design year)	15^{o} pos. range	2.82 ft-degree righting energy	Min. GZ passenger crowding	Min. GZ boat launch	Min. GZ wind loading	Max. angle static heel $<7^{o}$
FISHING/SHUTTLE						
80' fishing boat (1993)*	yes	yes	no	NA	yes	yes
59' fishing boat (1985)	yes	yes	no	NA	yes	yes
80' shuttle boat (1993)	yes	yes	yes	NA	yes	yes
DINNER/EXCURSION BOATS						
105' dinner boat (1988)	yes	yes	yes	NA	yes	yes
106' dinner boat (1993)	yes	yes	yes	NA	yes	yes
200' excursion boat (1993)	yes	yes	yes	NA	yes	yes
183' dinner boat (1988)	yes	yes	yes	NA	yes	yes
192' excursion boat (1986)	yes	yes	yes	NA	yes	yes
CASINO BOATS/PADDLE WHEELERS						
80' paddle wheeler (1986)	no	no	no	NA	yes	yes
198' casino boat (1993)	yes	yes	no	NA	yes	yes
228' casino boat (1993)	yes	yes	yes	NA	yes	yes
274' paddle wheeler (1983)	yes	yes	yes	NA	yes	yes

Table E.1 continues on next page

Table E.1 (cont.)
Compliance Summary

VESSEL	15^{0} pos. range	2.82 ft-degree righting energy	Min. GZ passenger crowding	Min. GZ boat launch	Min. GZ wind loading	Max. angle static heel $<7^{0}$
CONVERTED CREW BOATS						
91' crew boat A (1986)	yes	yes	yes	NA	yes	yes
91' crew boat B (1986)	yes	yes	no	NA	yes	yes
99' crew boat (1986)	yes	yes	yes	NA	yes	yes
102' crew boat (1987)	yes	yes	yes	NA	yes	yes
122' crew boat (1987)	yes	yes	no	NA	yes	no
PASSENGER CRUISE VESSEL						
180' cruise boat	yes	yes	yes	yes	yes	yes
FERRIES						
84' ferry (1988)	yes	yes	yes	NA	yes	yes
175' ferry (1982)	yes	yes	yes	NA	yes	yes
192' ferry (Sub chapter H)	yes	yes	yes	NA	yes	yes

* 80' fishing boat calculations were from "concept" drawings, using notional VCG of 9.00'.

NOTE: ***Results only for collision cases described in CFR are considered for this Table. Cases of groundings with extensive transverse damage conducted in the study, and not specified by CFR, are not included.***

1. INTRODUCTION

1.1 Purpose

This study investigates the efficacy of applying current international damage stability regulations to contemporary vessels typical of the United States domestic passenger fleet. The results will be used by the Coast Guard to help determine implementation for the new domestic regulations.

1.2 Background

The International Maritime Organization (IMO) adopted new amendments to the passenger ship damage stability regulations of the International Convention for the Safety of Life at Sea (SOLAS) in 1989, effective in 1990. They address regulatory shortcomings highlighted by several incidents at sea, notably the EUROPEAN GATEWAY and HERALD OF FREE ENTERPRISE disasters. The amendments modify SOLAS chapter II-1, regulation 8, paragraphs 2.3, 5, and 6.2, and add paragraph 2.4.

In short, the amendments specify righting energy (minimum of 2.82 foot-degrees), positive stability range (minimum of 15°), and residual righting arms (GZ) sufficient to sustain applied heeling moments from passenger crowding, wind loads, and lifeboat launching.

In September 1992, the Coast Guard issued final rules to incorporate the SOLAS amendments into the Code of Federal Regulations (46 CFR §171.070 "Subdivision requirements- Type II"). The new regulations were published in the 1992 Code of Federal Regulations, 46 CFR §171.080 and include an additional downflooding protection requirement. After a public hearing on August 5, 1993 during which industry's objections to the changes were heard, the Coast Guard suspended the revised regulations for a period of six months pending further input from affected industries and the results of this study.

Coast Guard then tasked the Volpe National Transportation Systems Center (Volpe Center) to investigate six new passenger vessel designs (80' fishing boat, 80' shuttle boat, 106' dinner boat, 200' excursion boat, and 198' and 228' casino boats) relative to the new regulations and to suggest structural and operational modifications to effect compliance where necessary. The results of an earlier study involving fifteen "T" and "H" craft are incorporated into this report.

The Coast Guard indefinitely extended the temporary suspension of the new regulations on February 25, 1994 and published a revised set of proposed rules on August 10, 1994. The most significant changes were: 1) a graduated schedule of heel angles for positive stability range and downflooding protection (5°, 10°, and 15°) tied to definitions of vessel service, vice 15° for all services; and 2) a similarly graduated set of coefficients (0.50 to 1.00) for calculation of the minimum righting arm to sustain applied heeling moments from passenger crowding and wind loads.

Final issue of this report was complete at the time of another public hearing on September 30, 1994.

2. APPROACH

A representative sampling of existing vessels and new passenger ship designs was chosen to reflect current trends, i.e., the proliferation of vessels targeted at the leisure market, such as dinner/excursion boats and afloat gambling casinos (see Table 2.1 for particulars). These vessels are designed to Type II subdivision requirements (46 CFR §171.070) for bulkhead arrangements, standard of flooding, and permeabilities; these specifications are used for the analysis. The damage stability of the twenty one vessels is evaluated by the new standards, which appear in 46 CFR §171.080(e) as a restatement of the 1990 SOLAS amendments.

2.1 Assumptions and Conditions

Application of the new regulations to the study vessels is based on the following assumptions and conditions:

Positive range

- All calculations are for seawater. Free communication is assumed for all damaged compartments. Stability calculations are by HECSALV (Herbert Engineering, San Francisco, California) using the lost buoyancy method.

Downflooding

- Available drawings were not clear on this point. Tightness of doors, hatches, and windows is not usually indicated and locations of other downflooding points such as air and tank vents are lacking. The issue is therefore not treated in the computer analysis, but is discussed in "Conclusions and Recommendations".

Heeling moments

<u>Passenger crowding</u>

- All passengers are initially placed in accordance with compartment distributions, per arrangement drawings. In the absence of such data, they are assumed to be initially at the vessel KG.
- Where the drawings identify "refuge" areas, they refer to fire safety standards, not muster areas such as exist on ocean-going cruise ships. Since the regulation lacks definition of such areas for small passenger vessels, some confusion may result in the application of this regulation.
- Two approaches to finding passenger crowding loads were utilized. For the first six vessels, the initial approach was to use available outside deck spaces, regardless of height, on a worst case basis, i.e., starting with the most outboard areas to produce the largest moments. Those on the outside decks are treated as relocated weights, including calculation of the rise in KG. If all available areas on one side cannot accommodate the full complement of passengers, those remaining were placed at the KG.

Table 2.1
Vessel Particulars

VESSEL	L_{pp}	Beam	Depth	Draft*	Δ* (LT)	PAX**
80' fishing boat	74'	24'	9.2'	2.50'	49	149
59' fishing boat	59'	20'	7.3'	3.17'	24	149
80' shuttle boat	73'	24'	11.7'	4.89'	89	200
105' dinner boat	105'	39'	9.3'	6.29'	288	600
106' dinner boat	102'	33'	7.5'	4.29'	299	550
200' excursion boat	200'	37'	14.4'	8.39'	770	800
192' excursion boat	153'	35'	10.4'	8.39'	782	600
183' dinner boat	183'	41'	11.0'	7.50'	551	600
80' paddle wheeler	80'	32'	7.0'	4.57'	182	500
198' casino boat	198'	60'	11.0'	6.47'	1837	1900
228' casino boat	228'	60'	13.0'	7.85'	2408	2500
274' paddle wheeler	274'	62'	8.5'	6.50'	1474	1200
91' crew boat A	91'	23'	9.2'	3.58'	58	250
91' crew boat B	91'	22'	9.5	3.31'	59	149
99' crew boat	90'	18'	9.0	3.61'	52	185
102' crew boat	102'	25'	10.0'	3.61'	69	150
122' crew boat	122'	21'	10.0'	4.69'	79	149
180' cruise boat, w/ lifeboats	180'	40'	12.7'	10.77'	658	112
84' ferry	84'	27'	3.5'	1.82'	86	90
175' ferry	175'	39'	14.0'	8.64'	522	1600
192' ferry	192'	66'	10.5'	6.4'	1355	3000

*** Departure condition** **** Passenger capacity**

- Coast Guard Headquarters later clarified the intent in a guidance letter (16703/46 CFR 171.080(e), July 20, 1993) as follows:

> passengers will "muster" to one side of the "deck(s) to which passengers go to assemble and depart the vessel in case of a flooding casualty" utilizing as much space as required, interior and exterior, for the rated load. If sufficient space does not exist, those remaining are considered as a point load on the centerline of the main deck.

The foregoing allows for various interpretations. For this study, passenger loads were kept as low as possible on decks with suitable egress, often resulting in smaller heeling arms than distributing passengers "to the rails" on all available decks. This approach served as a fallback for the first six vessels and the first option for evaluating the fifteen additional craft.

Wind loading

- Wind loading is per 46 CFR §171.080(e)(4)(iv), 2.51 lb/ft^2 acting on the projected lateral area in the intact condition, with a vertical lever to one half the intact draft.

Lifeboat launching

- Lifeboat launching loads specified by the SOLAS amendments pertain to davit boat handling systems and are applicable only to the 180' long passenger cruise vessel.

Intact conditions

- Damage stability was run for two intact conditions on each vessel: full load departure (100% passengers, 100% consumables, and 0% sewage) and "burn-out" return (100% passengers, 10% consumables, and 100% sewage). Additional conditions were added for the two larger ferries.
- Initial VCGs were calculated to include the vertical movement of passengers caused by the crowding requirement, whether up or down. Design center of gravity is referred to as VCG_o, shift due to passenger movement as GG_1, and resulting center as VCG_1.
- Specific volume of fresh water is taken as 35.88 ft^3/LT. Fuel is assumed to be diesel at specific gravity of 0.93 and specific volume of 38.58 ft^3/lt.

Damage extents

- Compartmentation standards are for "Type II" vessels per 46 CFR Tables 171.070(a) and 171.070(b) (for ferries only). 171.070(a) is reproduced below in Table 2.2 with corresponding study vessels, except ferries, for each standard. The 84' ferry has a one-compartment standard throughout; the 175' and 192' ferries are one-compartment ships except for two-compartment flooding at each end.

- Damage extents are given by 46 CFR 171.080(a) and (b) "Extent and Character of Damage", which describe damage from collisions. Grounding scenarios are not explicitly addressed. Damage extents for all subject vessels are:

    - Longitudinal- lesser of 35' or 10' + 0.03L.
    - Vertical- upward from baseline without limit.
    - Transverse- B/5.

- Damage cases investigated in this study include other instances of compartment and tank damage which could only be caused by groundings, involving some compartments inboard of the B/5 transverse collision penetration envelope. Maximum grounding damage extents were assumed within the "standard of flooding" envelope and all possible combinations of damage considered.

Software

- The "HECSALV" package of naval architecture software, by Herbert Engineering Corp., was used to analyze damaged stability.

The reader should note that the study was carried out using the rules as they originally appeared in the 1992 CFR and does not take account of the revisions published on August 10, 1994.

<u>**Table 2.2**</u>

"Table 171.070(a)- Standard of Flooding"

Passengers carried	**Part of vessel**	**Standard of flooding (compartments)**	**Vessels investigated**
400 or less	All.	1	80' dinner boat; 80' shuttle boat; all (7) crew boats; 59' fishing boat; and 180' cruise boat.
401 to 600	Forward of 1st MTWB aft of the collision bhd.	2*	105', 106' and 183' dinner boats, 192' dinner/excursion boat
401 to 600	All remaining portions of the vessel.	1	
601 to 800	Forward of 1st MTWB aft $0.4L_{pp}$.	2*	200' excursion boat
601 to 800	All remaining portions of the vessel.	1	
801 to 1000	Forward of 1st MTWB aft $0.6L_{pp}$.	2*	
801 to 1000	All remaining portions of the vessel.	1	
More than 1000	All.	2*	228' casino boat; 240' casino boat, and 274' paddle wheeler.

* Two compartment flooding means any two adjacent watertight compartments.

3. RESULTS

The software used includes the new SOLAS amendments in the damage stability module. The user however must figure wind load and passenger crowding moments, and calculate heeling arms and rises of VCG where applicable. Tables A-1, A-2, and A-3 (Appendix A) are spreadsheets for calculations of the moments.

Results for each vessel include a table showing calculations for "pre-damage" conditions, which are defined to include the effects of passenger movement specified by the crowding criterion. Intact displacement and VCG_0, rise of VCG due to passenger crowding (GG_1) and final VCG_1, heeling moment due to passenger crowding, and minimum required GZ are given. GZ_{reqd} is found by the equation:

$$GZ_{reqd} = 0.13' + (\text{moment(LT-ft)}/\Delta_{intact})$$

Damage stability summaries then appear for the full load departure and 90% burnout return conditions (DPRT and RTRN); results therein may be compared to the regulatory requirements and to the minimum righting arm requirement from the previous table. Non-compliant results are in bold face and underlined in the summary tables. Added grounding cases are italicized and non-compliant results therein likewise are bolded and underlined.

Particulars of each calculation are given, followed by modifications required to affect compliance, when needed.

It was not possible to thoroughly investigate 15° downflooding protection for two reasons. First, available drawings do not indicate tightness or sill heights of doors and hatchways; nor do they indicate air ducts, tank vents, and other openings. In addition, the chosen software calculates status of specified downflooding points only in positions of static equilibrium. It is clear in any case that designers and operators will have to carefully check these locations and the related operational requirements.

Spreadsheets to develop wind and passenger crowding heels are attached as Appendix A. Hydrostatics and full damage stability results are available separately upon request.

3.1 Fishing/shuttle boats

3.1.1 80' Fishing Boat (149 passengers)

This boat is investigated using the concept design draft (no trim assumed) and a notional VCG of nine feet. Appendage information was not available; the program default was used. All cases were symmetric flooding.

The boat is quite robust relative to static damaged heel, positive range, and righting energy. The controlling requirement for every damage condition is passenger crowding. The main deck

arrangement allows all passengers to crowd to one side, producing a large heeling arm and GZ_{reqd}. The 80' fishing boat nearly passes this requirement at the specified VCG (see Table 3.2), missing narrowly in one case only. The wind heel requirement is easily sustained. Its performance as a small passenger craft is excellent. No design or operational modifications are suggested.

Table 3.1
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Concept	49.0	9.00	0.00	9.00	73.05	1.62

Table 3.2
Damage Stability, Concept Design

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*Equilibrium Condition After Damage* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	DWLA001A	1	2.500	9.000	14.075	0.0	2.277	40.0	34.9	13.866	Yes
2	DWLA002A	2	2.500	9.000	14.075	0.0	2.397	40.0	37.0	14.527	Yes
3	DWLA003A	3	2.500	9.000	14.075	0.0	1.863	40.0	28.8	10.216	Yes
4	DWLA004A	4	2.500	9.000	14.075	2.5P	<u>1.559</u>	37.5	21.6	----	No
5	DWLA005A	6	2.500	9.000	14.075	0.0	1.895	40.0	25.0	8.741	Yes
6	DWLA006A	7	2.500	9.000	14.075	0.0	2.277	40.0	31.6	11.596	Yes

3.1.2 59' Fishing Boat (149 passengers)

This craft passes all requirements except passenger crowding heel. The mustering arrangement is on the main deck weather spaces only; accounting for 92 of 149 passengers. The VCG is lowered by removing all passengers from the upper deck to the main deck (DPTA and RTNA). There are two cases of failure in the return condition for: 1) damage to the engine room (max GZ misses by only 0.07'); and 2) damage to the unidentified "Compt 3", which misses by a large margin. All cases were symmetric flooding.

Two possible solutions were considered. Reduction of passenger capacity to reduce heeling moment for the relevant return condition leads to the following approximate calculation (working backwards from the minimum GZ_{max} from Case 3 return condition): 1) maximum available GZ = 1.07'; 2) heeling arm = 0.94'; 3) heeling moment = 35.91 LT-ft.; and 4) passenger capacity = 58-60 PAX, given the existing main deck design. This is probably unacceptable.

The designer could on the other hand add a subdivision bulkhead, roughly dividing the two compartments from 4'-36' aft of AP into three. This hypothetical modification (not shown) takes no account of the functions of these spaces, which are not indicated in the Coast Guard file, but does however solve the problem with no reduction of passenger capacity.

Table 3.3
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	44.3	9.53	-1.13	8.40	49.01	1.24
Return	38.2	10.52	-1.31	9.21	49.01	1.41

Table 3.4
59' Fishing Boat, Departure Condition

			Intact Condition			*------Equilibrium Condition------- -----------After Damage------------*					
Case No.	File	Damaged Compts	Mean draft (ft)	VCG (ft)	GMt (ft)	Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	DPTA001A	1	3.451	8.400	9.844	0.0	1.913	50.00	28.43	9.612	Yes
2	DPTA002A	2	3.451	8.400	9.844	0.0	1.817	50.00	26.16	8.199	Yes
3	DPTA003A	3	3.451	8.400	9.844	0.0	1.306	50.00	19.22	5.856	Yes
4	DPTA004A	5	3.451	8.400	9.844	0.0	1.516	50.00	20.99	5.928	Yes
5	DPTA005A	6	3.451	8.400	9.844	0.0	1.619	50.00	22.56	6.689	Yes

Table 3.5
59' Fishing Boat, Return Condition

			Intact Condition			*------Equilibrium Condition------- -----------After Damage------------*					
Case No.	File	Damaged Compts	Mean draft (ft)	VCG (ft)	GMt (ft)	Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTNA001A	1	3.236	9.210	11.088	0.0	1.657	50.00	27.04	10.800	Yes
2	RTNA002A	2	3.236	9.210	11.088	0.0	1.623	47.31	24.75	8.570	Yes
3	RTNA003A	3	3.236	9.210	11.088	0.0	1.073	45.26	17.68	6.427	No
4	RTNA004A	5	3.236	9.210	11.088	0.0	1.335	47.20	20.18	6.418	No
5	RTNA005A	6	3.236	9.210	11.088	0.0	1.454	48.96	21.89	7.327	Yes

3.1.3 80' Shuttle Boat

This boat passed all requirements in all damage conditions tested by substantial margins. Three damage cases involving service tanks resulted in small static heel angles; all others were symmetric flooding.

All passenger crowding was considered to take place on the upper deck, since no weather deck space exists on the main deck and most available interior space there is occupied by fixed tables and benches, with an aisle on the centerline. Seventy-nine passengers unaccounted for in this scenario were placed at vessel KG (nearly the same amount would be likewise placed if main deck crowding were assumed). This arrangement caused a considerable rise in VCG; the vessel none-the-less performed quite well.

Table 3.6
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	85.3	10.21	0.69	10.90	51.91	0.74
Return	79.4	10.66	0.74	11.40	51.91	0.78

Damage stability results follow:

Table 3.7
80' Shuttle Boat, Departure Condition

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*------Equilibrium Condition------- -----------After Damage------------* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	DPRT001A	1	4.887	10.900	8.560	0.0	1.800	40.0	51.9	8.435	Yes
2	DPRT002A	2	4.887	10.900	8.560	0.0	1.756	40.0	48.6	7.948	Yes
3	DPRT003A	3	4.887	10.900	8.560	0.0	1.542	40.0	39.9	6.352	Yes
4	DPRT004A	4	4.887	10.900	8.560	0.0	1.249	40.0	31.5	5.453	Yes
5	DPRT005A	6	4.887	10.900	8.560	0.2S	1.240	39.8	30.0	------	Yes
6	DPRT006A	7	4.887	10.900	8.560	0.2P	1.371	39.8	34.5	------	Yes
7	DPRT007A	7,8	4.887	10.900	8.560	0.8S	1.353	39.2	33.6	------	Yes
8	DPRT008A	4,5	4.887	10.900	8.560	0.0	1.321	38.7	32.5	5.997	Yes

Table 3.8
80' Shuttle Boat, Return Condition

Case No.	File	Damaged Compts	Intact Condition Mean draft (ft)	VCG (ft)	GMt (ft)	Equilibrium Condition After Damage Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTRN001B	1	4.701	11.400	8.873	0.0	1.670	40.0	48.6	8.751	Yes
2	RTRN002B	2	4.701	11.400	8.873	0.0	1.686	40.0	46.3	8.278	Yes
3	RTRN003B	3	4.701	11.400	8.873	0.0	1.449	40.0	37.2	6.535	Yes
4	RTRN004B	4	4.701	11.400	8.873	0.0	1.139	38.5	28.5	5.565	Yes
5	RTRN005B	6	4.701	11.400	8.873	0.1S	1.173	37.6	27.7	----	Yes
6	RTRN006B	7	4.701	11.400	8.873	0.2P	1.307	39.8	32.1	----	Yes
7	RTRN007B	7,8	4.701	11.400	8.873	0.2P	1.221	38.5	29.8	----	Yes
8	RTRN008B	4,5	4.701	11.400	8.873	0.0	1.370	40.0	34.0	5.959	Yes

3.2 Dinner/Excursion Boats

3.2.1 105' Dinner Boat (600 passengers)

Both this boat and the 106' dinner/excursion boat (3.2.2) are good tests of the new regulations because of its high passenger carrying capacity and relatively small size. Calculations showed that this vessel has very robust damage stability characteristics. It easily passed all the new requirements, including unrealistically high passenger crowding heeling arms. Table 3.9 gives two passenger heel scenarios: 1) lower moment from mustering on aft weather areas of the main and upper decks only; and 2) higher moments which include a large added muster area on the bridge deck. The latter is probably too high to be considered for safe removal and produces very high heeling arms. The boat however generates ample righting arms in all cases and still passes.

All damage cases are symmetric flooding except number 7, which includes a fuel tank on the shell.

Table 3.9
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	288.0	13.59	0.00	13.59	124.21/411.84	0.56/1.46
Return	279.0	13.68	0.00	13.68	124.21/411.84	0.58/1.50

Table 3.10
Damage Stability, Departure Condition

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*Equilibrium Condition After Damage* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	DPRT001A	1	6.290	13.540	18.015	0.0	4.037	48.73	61.22	17.922	Yes
2	DPRT002A	1,2	6.290	13.540	18.015	0.0	3.959	47.26	60.88	18.220	Yes
3	DPRT003A	2	6.290	13.540	18.015	0.0	3.967	47.63	60.90	18.185	Yes
4	DPRT004A	3	6.290	13.540	18.015	0.0	3.738	46.40	57.91	17.484	Yes
5	DPRT005A	4	6.290	13.540	18.015	0.0	2.646	38.38	43.22	15.976	Yes
6	DPRT006A	5	6.290	13.540	18.015	0.0	3.778	46.61	58.12	17.176	Yes
7	DPRT007A	5,7	6.290	13.540	18.015	0.6P	3.531	44.79	52.78	----	Yes
8	DPRT008A	10	6.290	13.540	18.015	0.0	3.023	41.49	48.20	15.477	Yes
9	DPRT009A	11	6.290	13.540	18.015	0.0	3.454	44.96	53.56	15.907	Yes
10	DPRT010A	12	6.290	13.540	18.015	0.0	3.515	45.43	53.95	15.699	Yes

Table 3.11
Damage Stability, Return Condition

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*Equilibrium Condition After Damage* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTRN001A	1	6.135	13.680	18.399	0.0	4.134	50.00	62.41	18.293	Yes
2	RTRN002A	1,2	6.135	13.680	18.399	0.0	4.112	48.08	62.67	18.609	Yes
3	RTRN003A	2	6.135	13.680	18.399	0.0	4.112	48.32	62.61	18.574	Yes
4	RTRN004A	3	6.135	13.680	18.399	0.0	3.889	47.12	59.73	17.855	Yes
5	RTRN005A	4	6.135	13.680	18.399	0.0	2.880	39.89	46.44	16.004	Yes
6	RTRN006A	5	6.135	13.680	18.399	0.0	3.889	47.17	59.46	17.487	Yes
7	RTRN007A	5,7	6.135	13.680	18.399	0.3S	3.634	45.60	55.21	----	Yes
8	RTRN008A	10	6.135	13.680	18.399	0.0	3.120	42.17	49.54	15.712	Yes
9	RTRN009A	11	6.135	13.680	18.399	0.0	3.537	45.47	54.64	16.183	Yes
10	RTRN010A	12	6.135	13.680	18.399	0.0	3.588	45.89	54.90	15.964	Yes

3.2.2 106' Dinner Boat (550 passengers)

The 106' dinner boat met all requirements by substantial margins. Nine damage cases in each condition were run, all resulting in symmetric flooding (drawings did not indicate service tanks). Omission of the tanks results in marginally less damage water in a few cases, but less free surface in most. Ignoring the

small free surface corrections does not appear to be a problem because GZ margins were quite substantial.

Passenger crowding was modeled by maximizing loads on available space on the main (398 passengers) and first upper (93 passengers) decks. The remainder were placed on the second upper deck (58 passengers). Other interpretations possible from the Coast Guard letter providing guidance on passenger distribution would result in even larger safety margins.

Table 3.12
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	299.5	11.70	1.10	12.80	351.83	1.30
Return	295.3	12.04	1.11	13.15	351.83	1.32

Table 3.13
Damage Stability, Departure Condition

			Intact Condition			------*Equilibrium Condition*------- -----------*After Damage*------------					
Case No.	File	Damaged Compts	Mean draft (ft)	VCG (ft)	GMt (ft)	Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv--ival?
1	DPRT001A	1	4.290	12.800	12.529	0.0	2.881	37.54	63.04	12.234	Yes
2	DPRT002A	2	4.290	12.800	12.529	0.0	2.421	35.07	50.77	11.309	Yes
3	DPRT003A	1,2	4.290	12.800	12.529	0.0	2.111	32.38	41.67	11.304	Yes
4	DPRT004A	3	4.290	12.800	12.529	0.0	1.915	31.76	37.28	9.856	Yes
5	DPRT005A	4	4.290	12.800	12.529	0.0	2.091	33.00	41.61	10.251	Yes
6	DPRT006A	5	4.290	12.800	12.529	0.0	1.766	30.58	33.02	9.460	Yes
7	DPRT007A	6	4.290	12.800	12.529	0.0	1.972	32.21	38.61	10.093	Yes
8	DPRT008A	7	4.290	12.800	12.529	0.0	1.721	30.36	32.29	9.969	Yes
9	DPRT009A	8	4.290	12.800	12.529	0.0	1.950	32.09	37.77	9.661	Yes

Table 3.14
Damage Stability, Return Condition

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*Equilibrium Condition After Damage* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTRN001B	1	4.240	13.150	12.428	0.0	2.863	36.84	61.34	12.084	Yes
2	RTRN002B	2	4.240	13.150	12.428	0.0	2.409	34.45	49.50	11.174	Yes
3	RTRN003B	1,2	4.240	13.150	12.428	0.0	2.107	31.88	40.87	11.176	Yes
4	RTRN004B	3	4.240	13.150	12.428	0.0	1.908	31.24	36.41	9.689	Yes
5	RTRN005B	4	4.240	13.150	12.428	0.0	2.085	32.42	40.58	10.076	Yes
6	RTRN006B	5	4.240	13.150	12.428	0.0	1.761	30.11	32.36	9.298	Yes
7	RTRN007B	6	4.240	13.150	12.428	0.0	1.970	31.70	37.82	9.945	Yes
8	RTRN008B	7	4.240	13.150	12.428	0.0	1.723	29.94	31.81	9.818	Yes
9	RTRN009B	8	4.240	13.150	12.428	0.0	1.946	31.60	37.02	9.514	Yes

3.2.3 200' Excursion Boat (800 passengers)

This vessel passed all new requirements; wide margins of compliance were observed except for one case of static heel (5°) close to the 7° maximum. It is noted that passenger crowding moments were quite low because of fixed furniture arrangements; only 327 of 800 passengers were accounted for, including use of available space on upper decks. Other interpretations of the Coast Guard guidance letter could result in even lower heeling moments and lower VCG.

There are many cases of asymmetrical flooding because of fuel, water, and lube oil tanks located proximate to the shell. Cases 12-15 are added grounding cases, which also passed.

Table 3.15
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	770.5	20.74	0.15	20.89	272.62	0.48
Return	737.7	20.98	0.16	21.14	272.62	0.50

Table 3.16

Damage Stability, Departure Condition

			Intact Condition			*------Equilibrium Condition------- -----------After Damage------------*					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv-ival?**
1	DPRT001A	1,2	8.395	20.890	7.247	0.0	2.065	40.0	58.7	7.071	Yes
2	DPRT002A	2,3	8.395	20.890	7.247	0.0	1.995	40.0	55.5	5.095	Yes
3	DPRT003A	3,4	8.395	20.890	7.247	0.0	1.882	40.0	51.6	4.349	Yes
4	DPRT004A	4,5	8.395	20.890	7.247	0.0	1.804	40.0	48.3	3.798	Yes
5	DPRT005A	6	8.395	20.890	7.247	0.0	1.892	40.0	53.4	5.509	Yes
6	DPRT006A	7	8.395	20.890	7.247	0.8S	2.183	39.2	62.1	----	Yes
7	DPRT007A	13	8.395	20.890	7.247	0.0	2.062	40.0	56.9	4.526	Yes
8	DPRT008A	14	8.395	20.890	7.247	0.0	1.935	40.0	53.5	5.476	Yes
9	DPRT009A	7,12	8.395	20.890	7.247	2.7S	1.731	37.3	46.9	----	Yes
10	DPRT010A	7,10	8.395	20.890	7.247	2.6S	1.805	37.4	48.9	----	Yes
11	DPRT011A	7,10,12	8.395	20.890	7.247	5.0S	1.334	35.0	33.4	----	Yes
12	*DPRT012A*	*7,9*	*8.395*	*20.890*	*7.247*	*0.0P*	*2.436*	*40.0*	*69.2*	*6.950*	*Yes*
13	*DPRT013A*	*7,9,10*	*8.395*	*20.890*	*7.247*	*1.6S*	*2.073*	*38.4*	*56.2*	*----*	*Yes*
14	*DPRT014A*	*7,9,12*	*8.395*	*20.890*	*7.247*	*1.6S*	*2.000*	*38.4*	*54.3*	*----*	*Yes*
15	*DPRT015A*	*7,9,10,12*	*8.395*	*20.890*	*7.247*	*3.6S*	*1.606*	*36.4*	*40.6*	*----*	*Yes*

Table 3.17

Damage Stability, Return Condition

			Intact Condition			*------Equilibrium Condition------- -----------After Damage------------*					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv-ival?**
1	RTRN001B	1,2	8.230	21.140	7.602	0.0	2.028	40.0	57.1	7.321	Yes
2	RTRN002B	2,3	8.230	21.140	7.602	0.0	1.929	40.0	53.7	5.053	Yes
3	RTRN003B	3,4	8.230	21.140	7.602	0.0	1.799	40.0	49.4	4.100	Yes
4	RTRN004B	4,5	8.230	21.140	7.602	0.0	1.699	40.0	46.0	3.947	Yes
5	RTRN005B	6	8.230	21.140	7.602	0.0	1.841	40.0	51.8	5.765	Yes
6	RTRN006B	7	8.230	21.140	7.602	0.8S	2.134	39.2	60.5	----	Yes
7	RTRN007B	13	8.230	21.140	7.602	0.0	1.991	40.0	54.6	4.710	Yes
8	RTRN008B	14	8.230	21.140	7.602	0.0	1.897	40.0	52.0	5.761	Yes
9	RTRN009B	7,12	8.230	21.140	7.602	0.7P	2.077	39.3	57.2	----	Yes
10	RTRN010B	7,10	8.230	21.140	7.602	0.2P	2.118	39.8	58.9	----	Yes
11	RTRN011B	7,10,12	8.230	21.140	7.602	2.0P	1.881	38.0	50.3	----	Yes
12	*RTRN012B*	*7,9*	*8.230*	*21.140*	*7.602*	*0.8S*	*2.182*	*39.2*	*59.6*	*----*	*Yes*
13	*RTRN013B*	*7,9,10*	*8.230*	*21.140*	*7.602*	*0.2P*	*2.168*	*39.8*	*60.3*	*----*	*Yes*
14	*RTRN014B*	*7,9,12*	*8.230*	*21.140*	*7.602*	*0.7P*	*2.126*	*39.3*	*58.5*	*----*	*Yes*
15	*RTRN015B*	*7,9,10,12*	*8.230*	*21.140*	*7.602*	*2.0P*	*1.925*	*38.0*	*51.5*	*----*	*Yes*

3.2.4 183' Dinner Boat (600 passengers)

All requirements are met by this vessel, including a very high passenger crowding heel, which is modeled on the upper deck since no main deck weather areas are available and egress there is very limited. 448 of 600 passengers are mustered out in this arrangement which is much more rigorous than that suggested by the Coast Guard guidance letter. The heeling arms are easily sustained.

Departure condition only was available from Coast Guard files.

Table 3.18
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	715.8	16.75	0.00	16.75	307.10	0.56

Table 3.19
Damage Stability, Departure Condition

			Intact Condition			*------Equilibrium Condition------- -----------After Damage-----------*					
Case No.	File	Damaged Compts	Mean draft (ft)	VCG (ft)	GMt (ft)	Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv -ival?
1	DPRT001A	1	7.500	16.750	7.419	0.0	1.856	32.92	27.27	7.449	Yes
2	DPRT002A	1,2	7.500	16.750	7.419	0.0	1.689	30.74	25.40	7.540	Yes
3	DPRT003A	2	7.500	16.750	7.419	0.0	1.712	31.37	25.53	7.368	Yes
4	DPRT004A	4	7.500	16.750	7.419	0.0	1.021	24.87	15.43	6.657	Yes
5	DPRT005A	2,3	7.500	16.750	7.419	0.0	1.617	30.30	25.02	7.999	Yes
6	DPRT006A	4,5	7.500	16.750	7.419	0.0	1.014	24.22	15.31	7.543	Yes
7	DPRT007A	6	7.500	16.750	7.419	0.0	1.398	29.39	21.24	6.495	Yes
8	DPRT008A	8	7.500	16.750	7.419	0.0	0.975	24.02	14.01	5.754	Yes
9	DPRT009A	10	7.500	16.750	7.419	0.0	0.785	21.19	10.38	6.021	Yes
10	DPRT010A	11	7.500	16.750	7.419	0.0	1.396	29.11	20.95	6.267	Yes
11	DPRT011A	11,12	7.500	16.750	7.419	0.0	1.274	27.25	19.27	6.575	Yes

3.2.5 192' Excursion Boat (600 passengers)

The 192' excursion boat is quite robust in damage stability, similar to others in its class. It passes all applicable SOLAS amendments by wide margins. Passenger crowding is modeled very conservatively, utilizing main, 01, and 02 levels (562 of 600 PAX); available GZ exceeds the requirement by wide margins in all cases.

All damage cases are symmetric flooding save one, where the fuel oil tank is on the shell (case 7).

Table 3.20
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	422.1	16.01	0.00	16.01	354.14	1.11
Return	414.5	15.99	0.00	15.99	154.14	1.13

Table 3.21
Damage Stability, Departure Condition

			Intact Condition			------*Equilibrium Condition*------- -----------*After Damage*------------					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv- -ival?**
1	DPRT001A	1	6.915	16.010	12.579	0.0	2.455	37.71	38.29	12.529	Yes
2	DPRT002A	1,2	6.915	16.010	12.579	0.0	2.383	35.70	37.36	12.668	Yes
3	DPRT003A	2	6.915	16.010	12.579	0.0	2.404	36.47	37.59	12.569	Yes
4	DPRT004A	3	6.915	16.010	12.579	0.0	2.091	34.20	32.99	11.359	Yes
5	DPRT005A	4	6.915	16.010	12.579	0.0	1.757	30.44	27.22	9.381	Yes
6	DPRT006A	5	6.915	16.010	12.579	0.0	2.298	35.61	35.56	11.268	Yes
7	DPRT007A	5,7	6.915	16.010	12.579	0.5P	2.136	34.25	32.39	----	Yes
8	DPRT008A	10	6.915	16.010	12.579	0.0	1.813	31.38	27.88	9.028	Yes
9	DPRT009A	11	6.915	16.010	12.579	0.0	2.084	34.34	32.12	10.079	Yes
10	DPRT010A	12	6.915	16.010	12.579	0.0	2.084	34.40	32.17	10.138	Yes

Table 3.22
Damage Stability, Return Condition

Case No.	File	Damaged Compts	Intact Condition Mean draft (ft)	VCG (ft)	GMt (ft)	Equilibrium Condition After Damage Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTRN001A	1	6.860	15.990	12.914	0.0	2.486	38.20	38.85	12.863	Yes
2	RTRN002A	1,2	6.860	15.990	12.914	0.0	2.414	36.14	37.92	13.005	Yes
3	RTRN003A	2	6.860	15.990	12.914	0.0	2.434	36.93	38.15	12.904	Yes
4	RTRN004A	3	6.860	15.990	12.914	0.0	2.123	34.69	33.57	11.668	Yes
5	RTRN005A	4	6.860	15.990	12.914	0.0	1.804	31.03	28.07	9.630	Yes
6	RTRN006A	5	6.860	15.990	12.914	0.0	2.343	36.17	36.32	11.569	Yes
7	RTRN007A	5,7	6.860	15.990	12.914	0.3S	2.201	35.01	33.76	----	Yes
8	RTRN008A	10	6.860	15.990	12.914	0.0	1.885	32.13	29.04	9.278	Yes
9	RTRN009A	11	6.860	15.990	12.914	0.0	2.143	34.98	33.02	10.359	Yes
10	RTRN010A	12	6.860	15.990	12.914	0.0	2.146	35.06	33.10	10.424	Yes

3.3 Casino Boats/Paddle Wheelers

3.3.1 80' Paddle Wheeler (500 passengers)

The beamy, shallow form typical of many river boats and long length of two subdivision compartments cause severe difficulties for compliance by this vessel. It fails requirements for positive righting range and energy from one-compartment damage to both the "Stores" ($0.23L_{pp}$) and Engine Room ($0.18L_{pp}$) compartments, as well as the passenger crowding heel specification.

For passenger crowding, utilizing available space on the main deck and 1st and 2nd upper decks caused failure in all damage cases for both departure and return conditions. Adopting a more limited approach, crowding on the main deck only, still resulted in failure for the two cases previously identified. Exterior and interior spaces on the main deck were considered; fixed furniture and poor access to doors limited the use of the interior space. Moreover, in one case, the statutory minimum GZ of 0.328' was not satisfied.

No attractive solution appears possible. Reduction of passenger capacity is probably not economically feasible as only 199 of 500 are accounted for in the crowding arrangement used; capacity of less than 199 would be required to substantially reduce the heeling arms. Subdivision of the Stores area would solve the problems for Case #8. The Engine Room would however present much greater difficulties, i.e., the machinery arrangement.

Table 3.23
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	243.8	12.75	0.00	12.75	95.99	0.29
Return	218.5	13.76	0.00	13.76	95.99	0.31

Table 3.24
Damage Stability, Departure Condition

			Intact Condition			------*Equilibrium Condition*------- -----------*After Damage*-------------					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv-ival?**
1	DPRT001A	1	4.798	12.757	6.921	0.0	1.277	27.3	19.4	6.904	Yes
2	DPRT002A	2	4.798	12.757	6.921	0.0	1.089	25.5	16.3	6.586	Yes
3	DPRT003A	1,2	4.798	12.757	6.921	0.0	0.940	22.6	13.3	6.687	Yes
4	DPRT004A	2,3	4.798	12.757	6.921	0.0	1.122	25.3	16.7	6.730	Yes
5	DPRT005A	1,2,3	4.798	12.757	6.921	0.0	0.955	22.2	13.2	6.840	Yes
6	DPRT006A	4	4.798	12.757	6.921	0.0	0.879	23.0	12.4	5.954	Yes
7	DPRT007A	6	4.798	12.757	6.921	0.0	0.805	21.9	10.8	5.528	Yes
8	DPRT008A	8	4.798	12.757	6.921	0.0	**0.283**	**11.2**	**2.0**	3.603	No
9	DPRT009A	10	4.798	12.757	6.921	0.0	0.392	**13.2**	3.2	4.632	No
10	DPRT010A	11	4.798	12.757	6.921	0.0	0.706	19.7	8.5	5.420	Yes
11	DPRT011A	12	4.798	12.757	6.921	0.0	0.851	21.8	11.3	5.678	Yes

Table 3.25
Damage Stability, Return Condition

			Intact Condition			*------Equilibrium Condition------- -----------After Damage------------*					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv- -ival?**
1	RTRN001A	1	4.340	13.690	7.027	0.0	1.476	28.5	22.2	6.962	Yes
2	RTRN002A	2	4.340	13.690	7.027	0.0	1.345	27.2	20.1	6.630	Yes
3	RTRN003A	1,2	4.340	13.690	7.027	0.0	1.316	26.8	19.6	6.672	Yes
4	RTRN004A	2,3	4.340	13.690	7.027	0.0	1.333	27.1	20.0	6.720	Yes
5	RTRN005A	1,2,3	4.340	13.690	7.027	0.0	1.282	26.0	19.0	6.779	Yes
6	RTRN006A	4	4.340	13.690	7.027	0.0	1.113	25.4	16.3	5.907	Yes
7	RTRN007A	6	4.340	13.690	7.027	0.0	0.990	24.0	14.0	5.417	Yes
8	RTRN008A	8	4.340	13.690	7.027	0.0	0.355	**13.2**	2.8	3.267	No
9	RTRN009A	10	4.340	13.690	7.027	0.0	**0.315**	**13.2**	**2.7**	4.523	No
10	RTRN010A	11	4.340	13.690	7.027	0.0	0.670	19.3	8.2	5.430	Yes
11	RTRN011A	12	4.340	13.690	7.027	0.0	0.809	21.0	10.7	5.719	Yes

3.3.2 198' Casino Boat (1900 passengers)

All requirements except residual GZ after passenger crowding were passed in all conditions examined (two compartment flooding throughout). One case involving flooding of compartments 4 and 5 caused failure to satisfy passenger heeling moments in both departure and return conditions, whether modeled with all passengers on one deck (according to the Coast Guard letter) or the more disadvantageous use of all decks. In all other damage cases, the vessel passed the requirement regardless of crowding arrangement used. Passenger heel is calculated with all on main deck. Cases 15-18 are added grounding scenarios.

The hold design configuration shows an uneven bulkhead spacing forward because of an unusually long compartment including a lounge, office spaces, and lavatories, adjacent to a "stores" compartment and "offices". Relocating a bulkhead for roughly even spacing solves the problem. Rearrangement of the accommodation-type spaces should present no design difficulties for a newbuilding. Figures 3.1 and 3.2 show the original and modified bulkhead arrangements; the critical damage case appears. Results in Tables 3.27 and 3.28 are for the modified arrangement.

Table 3.26
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	1837	27.80	0.00	27.80	2220.67	1.34
Return	1777	28.40	0.00	28.40	2220.67	1.38

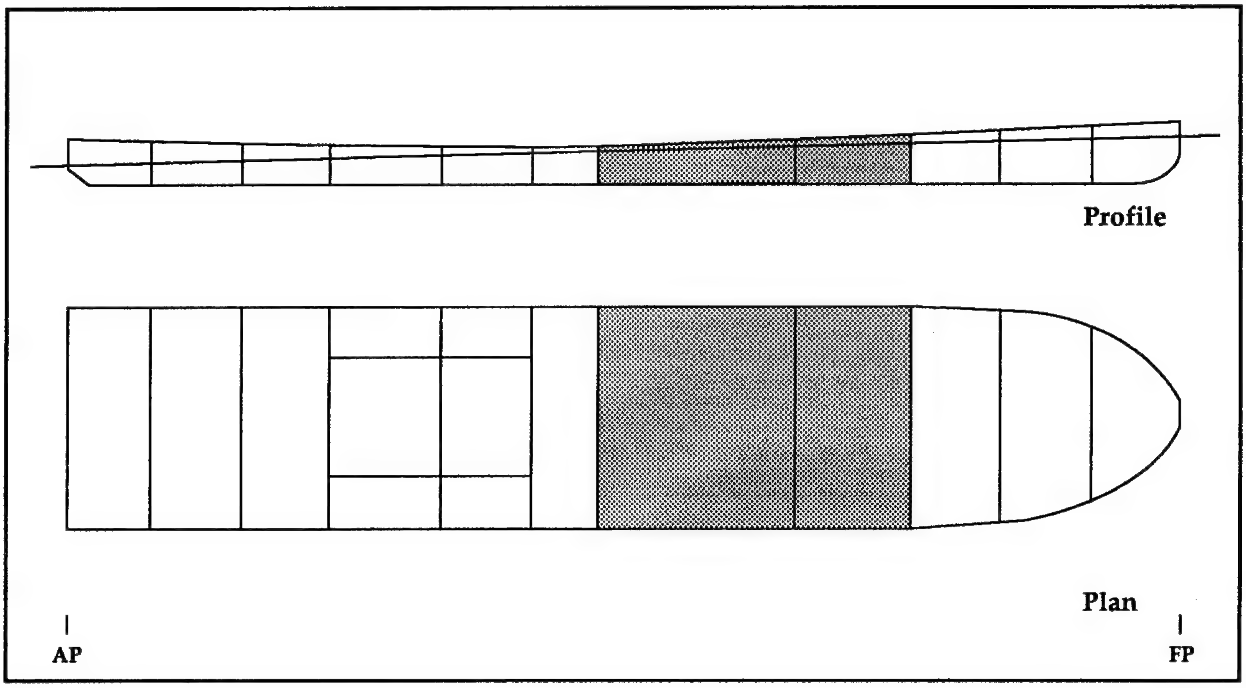


Figure 3.1
192' Casino Boat as Designed

Table 3.27
Damage Stability, Departure Condition
Modified Arrangement

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*Equilibrium Condition After Damage* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	DPRT001B	1,2	6.470	27.800	23.119	0.0	3.849	27.37	63.23	21.593	Yes
2	DPRT002B	2,3	6.470	27.800	23.119	0.0	2.902	24.68	44.15	18.686	Yes
3	DPRT003B	3,4	6.470	27.800	23.119	0.0	2.115	21.82	29.20	16.103	Yes
4	DPRT004B	4,5	6.470	27.800	23.119	0.0	1.807	20.46	23.45	14.372	Yes
5	DPRT005B	5,6	6.470	27.800	23.119	0.0	1.757	20.17	21.78	12.926	Yes
6	DPRT006B	6,7	6.470	27.800	23.119	2.1S	2.125	21.06	27.82	----	Yes
7	DPRT007B	6,9	6.470	27.800	23.119	2.1P	2.124	21.06	27.81	----	Yes
8	DPRT008B	7,10	6.470	27.800	23.119	0.5S	3.724	27.46	61.09	----	Yes
9	DPRT009B	9,12	6.470	27.800	23.119	0.5P	3.723	27.46	61.09	----	Yes
10	DPRT010B	10,13	6.470	27.800	23.119	0.9P	2.924	24.26	43.14	----	Yes
11	DPRT011B	12,13	6.470	27.800	23.119	0.9S	2.924	24.26	43.13	----	Yes
12	DPRT012B	13,14	6.470	27.800	23.119	0.0	1.808	20.29	23.43	15.419	Yes
13	DPRT013B	14,15	6.470	27.800	23.119	0.0	1.901	20.59	24.77	15.265	Yes
14	DPRT014B	4,5	6.470	27.800	23.119	0.0	1.807	20.46	23.45	14.372	Yes
15	*DPRT015B*	*11,8*	*6.470*	*27.800*	*23.119*	*0.0*	*4.522*	*28.84*	*77.82*	*23.370*	*Yes*
16	*DPRT016B*	*11,13*	*6.470*	*27.800*	*23.119*	*0.0*	*2.852*	*24.82*	*43.75*	*18.597*	*Yes*
17	*DPRT017B*	*10,11*	*6.470*	*27.800*	*23.119*	*0.9P*	*3.655*	*26.40*	*58.07*	*----*	*Yes*
18	*DPRT018B*	*11,12,13*	*6.470*	*27.800*	*23.119*	*0.7S*	*2.517*	*22.82*	*35.45*	*----*	*Yes*

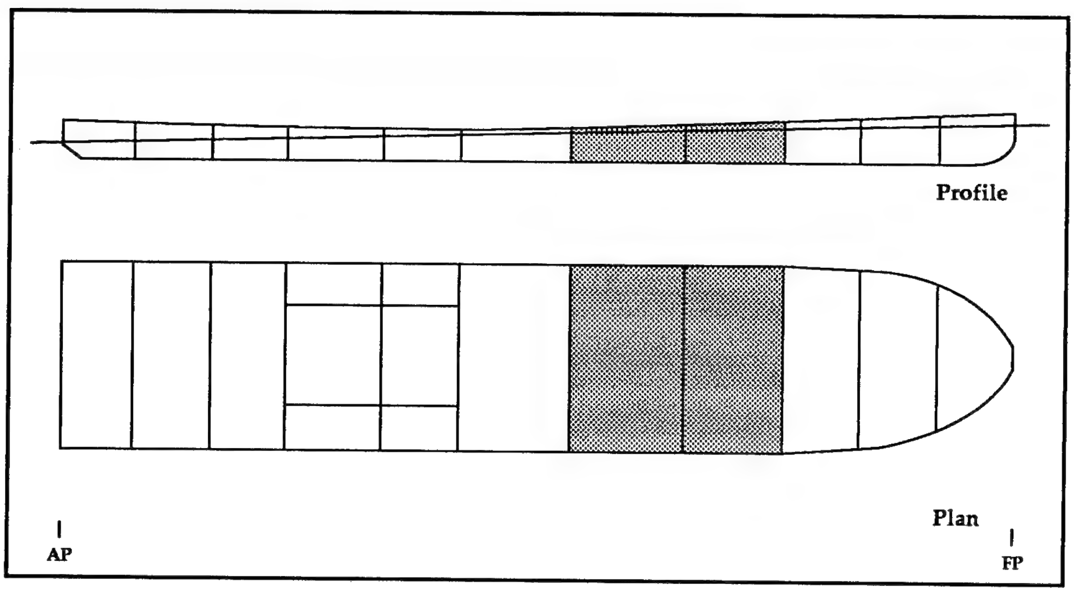


Figure 3.2
198' Casino Boat, Modified Arrangement

Table 3.28
Damage Stability, Return Condition
Modified Arrangement

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*Equilibrium Condition After Damage* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTRN001A	1,2	6.280	28.400	23.932	0.0	4.073	27.77	67.65	22.230	Yes
2	RTRN002A	2,3	6.280	28.400	23.932	0.0	3.125	25.21	48.26	19.143	Yes
3	RTRN003A	3,4	6.280	28.400	23.932	0.0	2.334	22.55	32.90	16.382	Yes
4	RTRN004A	4,5	6.280	28.400	23.932	0.0	2.004	21.29	26.80	14.775	Yes
5	RTRN005A	5,6	6.280	28.400	23.932	0.0	1.939	21.06	25.09	13.284	Yes
6	RTRN006A	6,7	6.280	28.400	23.932	1.1P	2.740	23.37	38.83	----	Yes
7	RTRN007A	6,9	6.280	28.400	23.932	1.1S	2.740	23.36	38.83	----	Yes
8	RTRN008A	7,10	6.280	28.400	23.932	0.5S	3.855	27.52	63.34	----	Yes
9	RTRN009A	9,12	6.280	28.400	23.932	0.5P	3.855	27.52	63.33	----	Yes
10	RTRN010A	10,13	6.280	28.400	23.932	2.1S	2.466	22.20	34.06	----	Yes
11	RTRN011A	12,13	6.280	28.400	23.932	2.1P	2.465	22.20	34.05	----	Yes
12	RTRN012A	13,14	6.280	28.400	23.932	0.0	2.046	21.36	27.66	15.934	Yes
13	RTRN013A	14,15	6.280	28.400	23.932	0.0	2.147	21.60	29.08	15.798	Yes
14	RTRN014A	4,5	6.280	28.400	23.932	0.0	2.004	21.29	26.80	14.775	Yes
15	*RTRN015A*	*11,8*	*6.280*	*28.400*	*23.932*	*0.0*	*4.197*	*28.62*	*72.52*	*22.605*	*Yes*
16	*RTRN016A*	*11,13*	*6.280*	*28.400*	*23.932*	*0.0*	*3.125*	*25.57*	*49.07*	*19.222*	*Yes*
17	*RTRN017A*	*10,11*	*6.280*	*28.400*	*23.932*	*1.6S*	*3.324*	*25.17*	*51.22*	----	*Yes*
18	*RTRN018A*	*11,12,13*	*6.280*	*28.400*	*23.932*	*2.3P*	*1.825*	*19.13*	*22.05*	----	*Yes*

3.3.3 228' Casino Boat (2500 passengers)

Calculations for this vessel were instructive because its passenger capacity is the highest of the study group. The boat is only 228' long and is designed with closely spaced transverse bulkheads; two compartment damage throughout its length is specified.

Damage cases included every possible combination of service tanks which could be affected by specified extents of collision damage; some grounding cases (nos. 6-13, 17, and 18) involving interior service tanks were added. Most cases resulted in symmetric flooding, while those involving service tanks resulted in minimal static heel angles (<0.3°).

This boat passed every regulation with ease, except that for residual GZ after passenger crowding. The initial approach placing passengers on the rails on all available decks caused failure in numerous cases; however, the boat passed by an interpretation of Coast Guard letter 16703/46 CFR 171.080(e), i.e., mustering as many passengers as possible on the main deck for evacuation by rescue craft, and placing

the rest on the centerline (these results shown). The initial approach resulted in greater transverse and vertical moments.

Table 3.29
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	2409	22.50	0.00	22.50	2471.46	1.16
Return	2346	22.50	0.00	22.50	2471.46	1.18

Table 3.30
Damage Stability, Departure Condition

			Intact Condition			------*Equilibrium Condition*------- -----------*After Damage*------------					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv-ival?**
1	DPRT001A	1,2	7.850	22.500	22.802	0.0	4.301	34.67	90.61	22.038	Yes
2	DPRT002A	2,3	7.850	22.500	22.802	0.0	3.028	29.48	56.14	19.591	Yes
3	DPRT003A	3,4	7.850	22.500	22.802	0.0	2.282	25.97	37.94	17.866	Yes
4	DPRT004A	4,5	7.850	22.500	22.802	0.0	2.140	25.62	35.26	17.653	Yes
5	DPRT005A	5,6	7.850	22.500	22.802	0.0	2.726	28.99	49.71	17.279	Yes
6	DPRT006A	5,6,7	7.850	22.500	22.802	0.0	2.858	28.99	51.90	17.677	Yes
8	DPRT008A	6,7,8	7.850	22.500	22.802	0.0	3.617	32.28	71.58	18.688	Yes
9	DPRT009A	6,8,11	7.850	22.500	22.802	0.0	3.232	31.23	62.60	18.107	Yes
10	DPRT010A	6,7,8,11	7.850	22.500	22.802	0.0	3.391	31.18	65.21	18.552	Yes
11	DPRT011A	6,7,8,11,10	7.850	22.500	22.802	0.2S	3.266	30.47	61.48	----	Yes
12	DPRT012A	6,8,11,10	7.850	22.500	22.802	0.2S	3.116	30.55	59.12	----	Yes
13	DPRT013A	6,8,10,7	7.850	22.500	22.802	0.3S	3.479	31.53	67.40	----	Yes
14	DPRT014A	6,8,10	7.850	22.500	22.802	0.2S	3.327	31.66	65.08	----	Yes
15	DPRT015A	8,12	7.850	22.500	22.802	0.0	3.300	31.57	64.24	17.823	Yes
16	DPRT016A	8,12,10	7.850	22.500	22.802	0.2S	3.181	30.87	60.66	----	Yes
17	DPRT017A	8,12,10,11	7.850	22.500	22.802	0.2S	2.959	29.59	54.03	----	Yes
18	DPRT018A	8,12,11	7.850	22.500	22.802	0.0	3.065	30.24	57.15	17.698	Yes
19	DPRT019A	12,13	7.850	22.500	22.802	0.0	2.692	28.50	47.24	16.389	Yes
20	DPRT020A	13,14	7.850	22.500	22.802	0.0	1.952	24.26	29.93	15.250	Yes
21	DPRT021A	14,15	7.850	22.500	22.802	0.0	1.755	23.18	26.11	15.132	Yes
22	DPRT022A	16,15	7.850	22.500	22.802	0.0	2.206	25.72	35.70	15.006	Yes

Table 3.31
Damage Stability, Return Condition

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*Equilibrium Condition After Damage* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTRN001B	1,2	7.680	22.500	23.692	0.0	4.608	35.72	99.40	22.860	Yes
2	RTRN002B	2,3	7.680	22.500	23.692	0.0	3.332	30.83	64.14	20.185	Yes
3	RTRN003B	3,4	7.680	22.500	23.692	0.0	2.574	27.61	45.28	18.347	Yes
4	RTRN004B	4,5	7.680	22.500	23.692	0.0	2.421	27.27	42.24	18.268	Yes
5	RTRN005B	5,6	7.680	22.500	23.692	0.0	2.988	30.28	56.70	17.950	Yes
6	*RTRN006B*	*5,6,7*	*7.680*	*22.500*	*23.692*	*0.0*	*2.779*	*29.02*	*50.83*	*17.941*	*Yes*
8	*RTRN008B*	*6,7,8*	*7.680*	*22.500*	*23.692*	*0.0*	*3.574*	*32.62*	*71.80*	*18.892*	*Yes*
9	*RTRN009B*	*6,8,11*	*7.680*	*22.500*	*23.692*	*0.0*	*3.961*	*33.31*	*80.14*	*19.647*	*Yes*
10	*RTRN010B*	*6,7,8,11*	*7.680*	*22.500*	*23.692*	*0.0*	*3.793*	*32.50*	*75.41*	*19.568*	*Yes*
11	*RTRN011B*	*6,7,8,11,10*	*7.680*	*22.500*	*23.692*	*0.4P*	*3.526*	*31.27*	*67.85*	----	*Yes*
12	*RTRN012B*	*6,8,11,10*	*7.680*	*22.500*	*23.692*	*0.4P*	*3.697*	*32.15*	*72.66*	----	*Yes*
13	*RTRN013B*	*6,8,10,7*	*7.680*	*22.500*	*23.692*	*0.4P*	*3.319*	*31.37*	*64.49*	----	*Yes*
14	RTRN014B	6,8,10	7.680	22.500	23.692	0.4P	3.486	32.30	69.37	----	Yes
15	RTRN015B	8,12	7.680	22.500	23.692	0.0	3.589	32.76	72.15	18.541	Yes
16	RTRN016B	8,12,10	7.680	22.500	23.692	0.4P	3.333	31.51	64.81	----	Yes
17	*RTRN017B*	*8,12,10,11*	*7.680*	*22.500*	*23.692*	*0.4P*	*3.545*	*31.43*	*68.28*	----	*Yes*
18	*RTRN018B*	*8,12,11*	*7.680*	*22.500*	*23.692*	*0.0*	*3.813*	*32.66*	*75.88*	*19.203*	*Yes*
19	RTRN019B	12,13	7.680	22.500	23.692	0.0	2.970	29.96	54.85	17.060	Yes
20	RTRN020B	13,14	7.680	22.500	23.692	0.0	2.226	26.11	36.69	15.891	Yes
21	RTRN021B	14,15	7.680	22.500	23.692	0.0	2.044	25.07	32.69	15.783	Yes
22	RTRN022B	16,15	7.680	22.500	23.692	0.0	2.518	27.39	42.91	15.688	Yes

3.3.4 274' Paddle Wheeler (1200 passengers)

The 274' paddle wheeler has roughly the length and beam dimensions of the two casino boats studied, but is much shallower (D=8.5' vice 11.0' and 13.0') and has less freeboard (fb=2.0' vice 4.5' and 5.1'). It is thus very effective in symmetric flooding situations, but tends to heel much more sharply in asymmetric cases (see cases 5 and 6).

The hold arrangement is unique among the group of vessels studied, first because there are substantial areas forward with a double bottom. There are two sets of port and starboard "wing" voids, one 80' long by 17' wide centered roughly amidships and the other a partially foamed 40' X 12' space extending to the aft perpendicular. Each of the critical heeled damage cases involve one of the amidships voids.

Cases one through nine are collision damage scenarios arising from the CFR two-compartment standard. Cases ten through fifteen were added to see the effect of groundings involving wider transverse damage extents and more "appended" compartments, i.e., service tanks inboard of B/5 from the shell.

Every collision case except one passed all damage stability requirements. The exception (departure case 5, including the amidships void) failed only because its positive range was 14.5°, 0.5° short of the requirement. This could be easily remedied by slight loading modifications or some application of foam in those void spaces. For crowding heel, passengers were distributed on main and upper decks (788 out of 1200). Grounding cases include two instances of capsize in each condition.

Table 3.32
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	1674	19.67	0.00	19.67	970.5	0.71
Return	1606	20.19	0.00	20.19	970.5	0.73

Table 3.33 - Damage Stability, Departure Condition

			Intact Condition			*------Equilibrium Condition------- -----------After Damage-------------*					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv- -ival?**
1	DPRT001A	1,2	6.490	19.670	42.591	0.0	6.858	40.0	113.3	41.842	Yes
2	DPRT002A	2,3	6.490	19.670	42.591	0.0	5.929	37.8	99.8	42.374	Yes
3	DPRT003A	3,7	6.490	19.670	42.591	0.0	5.385	36.2	90.1	41.090	Yes
4	DPRT004A	7,10	6.490	19.670	42.591	0.0	4.677	33.8	78.6	42.580	Yes
5	DPRT005A	10,11	6.490	19.670	42.591	5.1S	1.089	14.5	10.4	----	No
6	DPRT006A	11,15	6.490	19.670	42.591	4.5S	1.491	17.6	17.2	----	Yes
7	DPRT007A	15,16,17	6.490	19.670	42.591	0.2S	4.978	35.0	83.0	----	Yes
8	DPRT008A	16,17,19	6.490	19.670	42.591	0.1S	5.565	37.1	93.6	----	Yes
9	DPRT009A	16,17,19,18	6.490	19.670	42.591	0.2S	3.517	28.7	57.5	----	Yes
10	*DPRT010A*	*2,3,4*	*6.490*	*19.670*	*42.591*	*0.0*	*5.903*	*37.7*	*99.4*	*42.795*	*Yes*
11	*DPRT011A*	*10,11,12,13*	*6.490*	*19.670*	*42.591*	*90.0S*	*- 0.824*	*0.0*	*0.0*	----	*Capsize*
12	*DPRT012A*	*10,12,13*	*6.490*	*19.670*	*42.591*	*0.0*	*4.211*	*31.5*	*71.1*	*50.272*	*Yes*
13	*DPRT013A*	*13,14,15*	*6.490*	*19.670*	*42.591*	*0.0*	*4.643*	*33.3*	*79.1*	*44.678*	*Yes*
14	*DPRT014A*	*13,14,15,11*	*6.490*	*19.670*	*42.591*	*90.0S*	*-0.335*	*0.0*	*0.0*	----	*Capsize*
15	*DPRT015A*	*15,16,17,18*	*6.490*	*19.670*	*42.591*	*0.6S*	*2.460*	*23.7*	*36.9*	----	*Yes*

Table 3.34 - Damage Stability, Return Condition

			Intact Condition			Equilibrium Condition After Damage					
Case No.	File	Damaged Compts	Mean draft (ft)	VCG (ft)	GMt (ft)	Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTRN001B	1,2	6.225	20.190	43.596	0.0	7.255	40.0	119.0	43.326	Yes
2	RTRN002B	2,3	6.225	20.190	43.596	0.0	6.468	38.7	108.1	42.108	Yes
3	RTRN003B	3,7	6.225	20.190	43.596	0.0	5.927	37.4	98.7	40.569	Yes
4	RTRN004B	7,10	6.225	20.190	43.596	0.0	5.219	35.1	87.1	39.720	Yes
5	RTRN005B	10,11	6.225	20.190	43.596	5.0S	1.422	16.4	15.3	----	Yes
6	RTRN006B	11,15	6.225	20.190	43.596	4.5S	1.603	18.2	19.1	----	Yes
7	RTRN007B	15,16,17	6.225	20.190	43.596	0.2S	5.144	35.2	85.7	----	Yes
8	RTRN008B	16,17,19	6.225	20.190	43.596	0.2S	5.768	37.3	96.3	----	Yes
9	RTRN009B	16,17,19,18	6.225	20.190	43.596	0.3S	3.526	28.6	57.4	----	Yes
10	*RTRN010B*	*2,3,4*	*6.225*	*20.190*	*43.596*	*0.0*	*6.445*	*38.7*	*107.9*	*42.165*	*Yes*
11	*RTRN011B*	*10,11,12,13*	*6.225*	*20.190*	*43.596*	***90.0S***	***-0.394***	***0.0***	***0.0***	----	*Capsize*
12	*RTRN012B*	*10,12,13*	*6.225*	*20.190*	*43.596*	*0.0*	*4.731*	*33.0*	*80.0*	*48.314*	*Yes*
13	*RTRN013B*	*13,14,15*	*6.225*	*20.190*	*43.596*	*0.0*	*4.895*	*33.8*	*83.8*	*44.574*	*Yes*
14	*RTRN014B*	*13,14,15,11*	*6.225*	*20.190*	*43.596*	***90.0S***	***-0.249***	***0.0***	***0.0***	----	*Capsize*
15	*RTRN015B*	*15,16,17,18*	*6.225*	*20.190*	*43.596*	*0.7S*	*2.438*	*23.6*	*36.9*	----	*Yes*

3.4 Converted Crew Boats

3.4.1 91' Crew Boat A (250 passengers)

The selected load configuration was "deep draft, excursion permit only" (as described by the design naval architect) for 250 passengers. All the new requirements were passed in departure and return conditions. All cases of one-compartment flooding were symmetric except two involving either of paired fuel tanks on the shell. The relatively high freeboard of 5.6' lends to the robust righting characteristics of this vessel.

Table 3.35
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	102.1	9.81	0.00	9.81	51.19	0.63
Return	88.2	10.24	0.00	10.24	51.19	0.71

The passenger crowding load was modeled only on exposed weather areas of the main deck; 92 of 250 passengers are "on the rails" for the calculation. There is limited space available on the upper deck which was not considered; the damage stability results indicate capacity to sustain a higher crowding moment.

Table 3.36
Damage Stability, Departure Condition

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*Equilibrium Condition After Damage* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	DPRT001A	1	3.875	9.810	4.250	0.0	1.250	50.00	15.71	4.250	Yes
2	DPRT002A	2	3.875	9.810	4.250	0.0	1.326	48.97	16.04	4.022	Yes
3	DPRT003A	3	3.875	9.810	4.250	0.0	0.835	42.03	9.36	1.946	Yes
4	DPRT004A	4	3.875	9.810	4.250	0.0	1.232	50.00	15.74	4.228	Yes
5	DPRT005A	5	3.875	9.810	4.250	2.3P	0.882	45.14	10.51	----	Yes
6	DPRT006A	4,5	3.875	9.810	4.250	2.2P	0.893	44.32	10.86	----	Yes
7	DPRT007A	7	3.875	9.810	4.250	0.0	0.721	41.26	9.58	2.449	Yes
8	DPRT008A	8	3.875	9.810	4.250	0.0	0.903	43.28	11.51	2.918	Yes

Table 3.37
Damage Stability, Return Condition

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*Equilibrium Condition After Damage* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTRN001B	1	3.575	10.240	4.960	0.0	1.155	50.00	16.32	4.956	Yes
2	RTRN002B	2	3.575	10.240	4.960	0.0	1.237	48.24	16.80	4.715	Yes
3	RTRN003B	3	3.575	10.240	4.960	0.0	0.800	42.48	9.43	2.145	Yes
4	RTRN004B	4	3.575	10.240	4.960	0.0	1.159	50.00	16.42	4.916	Yes
5	RTRN005B	5	3.575	10.240	4.960	1.6S	1.036	48.43	12.66	----	Yes
6	RTRN006B	4,5	3.575	10.240	4.960	1.6S	1.040	48.40	12.94	----	Yes
7	RTRN007B	7	3.575	10.240	4.960	0.0	0.788	42.96	10.29	2.703	Yes
8	RTRN008B	8	3.575	10.240	4.960	0.0	0.942	44.69	12.22	3.278	Yes

3.4.2 91' Crew Boat B (150 passengers)

91' crew boat "B" is quite similar in size and form to 91' crew boat "A". As such, it is informative on a number of points regarding the critical damage stability requirement of passenger crowding heel, which it fails. Boat "B" passes all other requirements with ease.

Passenger crowding is modeled on ample available weather spaces on the main deck; 142 of 150 passengers are thus accounted for. Compliance is achieved in the departure condition, but the VCG rises nearly a foot in the return condition and contributes to three cases of failure, one of which is asymmetric (fuel tank and the auxiliary engine room). GZ_{reqd} is also higher by 0.12' in the return condition.

No easy solution presents itself for redress of this failure to comply. Foaming in the low void space beneath the "passengers" compartment (case # 3) would help; further subdivision there, though difficult, would also work. Such options are probably not feasible in the auxiliary machinery space (cases # 4 and 6) since the fuel tanks occupy the low void spaces and rearrangement of equipment is difficult. Calculating backwards to get sustainable heeling arms results in a reduction of passenger capacity to 68 (RTN2); this would probably be economically unacceptable. The additional run was made assuming that initial conditions were unchanged; Table 3.40 results therefore apply, except that GZ_{reqd} is 0.48'.

The cases of the two 91' crew boats are illustrative on two points, if one observes that "A" passes passenger crowding while "B" fails. The hulls are very similar in proportion and displacement, yet "B" is subject to larger heeling moments. Two inferences follow:

- Boats with higher proportions of passengers to displacement are more likely to fail.
- More particularly in this case, deck arrangements and modeling of mustered passengers often determine the efficacy of compliance. While "A" meets the requirement, "B" fails in spite of carrying fewer passengers because it has more available muster area.

Table 3.38
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	83.7	7.88	0.00	7.88	64.29	0.90
Return	72.4	8.84	0.00	8.84	64.29	1.02
RTN2 (68 PAX)	72.4	8.84	0.00	8.84	25.34	0.48

Finally, 91' crew boat "B" illuminates a problem with the wording in 46 CFR 171.080(e) relative to the SOLAS amendments. Para. (e)4 reads "Each vessel must have a maximum righting arm within 15° of the angle of equilibrium..." and then describes the various heeling scenarios to be met. In many damage

cases for this boat, the necessary GZ is attained but not within 15°. SOLAS, on the other hand, does not limit the angle of maximum GZ. Coast Guard Headquarters indicates that this distinction was not intended and that the language in the rule needs to be reviewed.

Table 3.39
Damage Stability, Departure Condition

			Intact Condition			------*Equilibrium Condition*------- -----------*After Damage*------------					
Case No.	File	Damaged Compts	Mean draft (ft)	VCG (ft)	GMt (ft)	Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv--ival?
1	DPRT001A	1	3.310	7.880	5.243	0.0	1.732	50.00	17.83	5.192	Yes
2	DPRT002A	2	3.310	7.880	5.243	0.0	1.738	50.00	18.59	4.995	Yes
3	DPRT003A	3	3.310	7.880	5.243	0.0	1.361	50.00	13.06	3.192	Yes
4	DPRT004A	4	3.310	7.880	5.243	0.0	1.351	50.00	12.56	3.185	Yes
5	DPRT005A	5	3.310	7.880	5.243	0.0	1.837	50.00	19.27	5.608	Yes
6	DPRT006A	4,5	3.310	7.880	5.243	0.0	1.452	50.00	13.59	3.445	Yes
7	DPRT007A	7	3.310	7.880	5.243	0.0	1.545	50.00	15.13	4.049	Yes
8	DPRT008A	8	3.310	7.880	5.243	0.0	1.551	50.00	15.63	4.236	Yes
9	DPRT009A	8,9	3.310	7.880	5.243	0.0	1.573	50.00	16.20	4.395	Yes
10	DPRT010A	9	3.310	7.880	5.243	0.0	1.675	50.00	18.39	5.378	Yes

Table 3.40
Damage Stability, Return Condition

			Intact Condition			------*Equilibrium Condition*------- -----------*After Damage*------------					
Case No.	File	Damaged Compts	Mean draft (ft)	VCG (ft)	GMt (ft)	Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv--ival?
1	RTRN001B	1	3.050	8.840	5.223	0.0	1.177	50.00	15.30	5.169	Yes
2	RTRN002B	2	3.050	8.840	5.223	0.0	1.236	50.00	16.27	5.088	Yes
3	RTRN003B	3	3.050	8.840	5.223	0.0	0.500	50.00	7.93	1.955	No
4	RTRN004B	4	3.050	8.840	5.223	0.0	0.845	50.00	10.48	2.796	No
5	RTRN005B	5	3.050	8.840	5.223	2.8S	1.347	47.19	12.60	----	Yes
6	RTRN006B	4,5	3.050	8.840	5.223	4.7S	0.983	45.27	7.38	----	No
7	RTRN007B	7	3.050	8.840	5.223	0.0	1.095	50.00	12.71	3.712	Yes
8	RTRN008B	8	3.050	8.840	5.223	0.0	1.091	50.00	13.09	4.034	Yes
9	RTRN009B	8,9	3.050	8.840	5.223	0.0	1.195	50.00	14.26	4.169	Yes

3.4.3 99' Crew Boat (185 passengers)

The 100' crew boat passed all the new SOLAS amendments, including passenger crowding heel. All flooding cases except three are symmetric, those exceptions involving small service tanks within the B/5 envelope and resulting small angles of heel. Again, a large freeboard of 5.4' contributes to the craft's robustness.

Only main deck weather areas were used for passenger crowding; accounting for 120 of 185 passengers. Main deck interior and upper deck spaces were unsuitable for evacuation. The boat failed in several cases to sustain the heeling moment, using the design VCGs. Accounting for movement of all passengers to the main deck however lowered the VCGs and was sufficient to achieve compliance without design modifications or passenger reduction. Results from the latter case are shown.

Table 3.41
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	77.7	8.63	-0.47	8.16	58.23	0.88
Return	70.3	9.01	-0.51	8.50	58.23	0.96

The assumption that all passengers not crowding to one side are placed on the centerline of the evacuation deck can probably be justified in this case, given the furniture arrangement and egress available in the main deck cabin. Such an assumption will not always hold true however and should be verified in each case.

Table 3.42
Damage Stability, Departure Condition

			Intact Condition			------*Equilibrium Condition*------- -----------*After Damage*------------					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv-ival?**
1	DPTA001A	1	3.610	8.160	5.139	0.0	1.695	50.00	18.69	5.198	Yes
2	DPTA002A	2	3.610	8.160	5.139	0.0	1.687	50.00	18.85	4.988	Yes
3	DPTA003A	4	3.610	8.160	5.139	0.0	1.369	50.00	13.29	3.066	Yes
4	DPTA004A	5	3.610	8.160	5.139	0.0	1.215	50.00	12.44	3.348	Yes
5	DPTA005A	5,6	3.610	8.160	5.139	0.3P	0.965	49.73	10.02	----	Yes
6	DPTA006A	5,6,7	3.610	8.160	5.139	1.7P	0.903	48.33	8.61	----	Yes
7	DPTA007A	5,7	3.610	8.160	5.139	1.1P	1.164	48.92	11.19	----	Yes
8	DPTA008A	10	3.610	8.160	5.139	0.0	1.425	50.00	14.89	3.630	Yes

Table 3.43
Damage Stability, Return Condition

Case No.	File	Damaged Compts	Intact Condition: Mean draft (ft)	VCG (ft)	GMt (ft)	Equilibrium Condition After Damage: Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTNA001A	1	3.440	8.500	5.528	0.0	1.539	50.00	18.72	5.615	Yes
2	RTNA002A	2	3.440	8.500	5.528	0.0	1.528	50.00	18.90	5.413	Yes
3	RTNA003A	4	3.440	8.500	5.528	0.0	1.256	50.00	13.20	3.205	Yes
4	RTNA004A	5	3.440	8.500	5.528	0.0	1.163	50.00	12.49	3.464	Yes
5	RTNA005A	5,6	3.440	8.500	5.528	4.1S	1.090	45.92	8.23	----	Yes
6	RTNA006A	5,6,7	3.440	8.500	5.528	3.9S	1.070	46.06	8.21	----	Yes
7	RTNA007A	5,7	3.440	8.500	5.528	0.1P	1.156	49.89	12.35	----	Yes
8	RTNA008A	10	3.440	8.500	5.528	0.0	1.385	50.00	14.78	3.791	Yes

3.4.4 102' Crew Boat (150 passengers)

Compliance was achieved in all cases for departure and return conditions. This is a good sized vessel with ample freeboard (6.4') carrying a relatively low number of passengers. GZ_{max} ranges from 1.96 to 3.03 times those required, positive range for all cases is at or above 50°, and righting energies are more than ample. Several cases involving service tank damage result in small heel angles.

All passengers are accounted for in the crowding modeled on the main deck. Reduction of VCG for passenger movement is not calculated because of the wide margins by which the boat complies.

Table 3.44
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	105.1	7.86	0.00	7.86	90.25	1.00
Return	84.5	8.38	0.00	8.38	90.25	1.21

Table 3.45
Damage Stability, Departure Condition

Case No.	File	Damaged Compts	Intact Condition Mean draft (ft)	VCG (ft)	GMt (ft)	Equilibrium Condition After Damage Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	DPRT001A	1	3.650	7.860	11.300	0.0	3.034	50.0	35.4	11.429	Yes
2	DPRT002A	2	3.650	7.860	11.300	0.0	3.032	50.0	36.3	11.289	Yes
3	DPRT003A	3	3.650	7.860	11.300	0.0	2.488	50.0	29.2	8.064	Yes
4	DPRT004A	8	3.650	7.860	11.300	0.0	2.590	50.0	29.0	8.040	Yes
5	DPRT005A	9	3.650	7.860	11.300	0.0	2.872	50.0	32.7	9.623	Yes
6	DPRT006A	10	3.650	7.860	11.300	0.0	2.958	50.0	34.1	10.533	Yes
7	DPRT007A	4,6	3.650	7.860	11.300	0.1S	2.521	49.9	32.4	----	Yes
8	DPRT008A	4,6,5	3.650	7.860	11.300	0.0S	2.617	50.0	33.7	12.138	Yes
9	DPRT009A	4	3.650	7.860	11.300	0.3S	2.576	49.7	29.3	----	Yes
10	DPRT010A	6	3.650	7.860	11.300	0.0	2.913	50.0	37.5	13.535	Yes
11	DPRT011A	7	3.650	7.860	11.300	1.5P	2.551	48.5	26.4	----	Yes
12	DPRT012A	6,7	3.650	7.860	11.300	1.3P	2.513	48.7	28.9	----	Yes
13	DPRT013A	5,6	3.650	7.860	11.300	0.0P	2.606	50.0	33.0	12.758	Yes
14	DPRT014A	4,5	3.650	7.860	11.300	0.3S	2.654	49.7	30.3	----	Yes

Table 3.46
Damage Stability, Return Condition

Case No.	File	Damaged Compts	Intact Condition Mean draft (ft)	VCG (ft)	GMt (ft)	Equilibrium Condition After Damage Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTRN001B	1	3.240	8.380	12.570	0.0	2.954	50.0	35.8	13.065	Yes
2	RTRN002B	2	3.240	8.380	12.570	0.0	2.966	50.0	37.2	13.618	Yes
3	RTRN003B	3	3.240	8.380	12.570	0.0	2.370	50.0	30.0	9.571	Yes
4	RTRN004B	8	3.240	8.380	12.570	0.0	2.562	50.0	29.7	9.250	Yes
5	RTRN005B	9	3.240	8.380	12.570	0.0	2.830	50.0	33.4	10.658	Yes
6	RTRN006B	10	3.240	8.380	12.570	0.0	2.906	50.0	34.6	11.723	Yes
7	RTRN007B	4,6	3.240	8.380	12.570	0.0S	2.551	50.0	32.7	11.586	Yes
8	RTRN008B	4,6,5	3.240	8.380	12.570	1.2S	2.545	48.8	29.6	----	Yes
9	RTRN009B	4	3.240	8.380	12.570	0.0	2.512	50.0	30.5	11.772	Yes
10	RTRN010B	6	3.240	8.380	12.570	0.0	2.954	50.0	37.8	13.420	Yes
11	RTRN011B	7	3.240	8.380	12.570	1.2P	2.496	48.8	27.0	----	Yes
12	RTRN012B	6,7	3.240	8.380	12.570	1.3P	2.542	48.7	29.2	----	Yes
13	RTRN013B	5,6	3.240	8.380	12.570	0.9S	2.968	49.1	34.9	----	Yes
14	RTRN014B	4,5	3.240	8.380	12.570	1.1S	2.500	48.9	27.4	----	Yes

3.4.5 122' Crew Boat (149 passengers)

All new SOLAS requirements are met by this vessel, which succeeds due to high freeboard and low passenger capacity relative to its size. Mustered passengers (all 149) were modeled on the main deck, producing sustainable heeling arms for both conditions. It should be noted that an initial set of calculations, in which GG_1 due to downward movement of passengers was not accounted for, included several cases of failure. The second set corrects the error and results in success.

Cases #9 and 10 are hypothetical grounding damages of wide transverse extent including tanks inboard of B/5. These also pass.

Table 3.47
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	131.2	7.25	-0.61	6.64	57.05	0.56
Return	96.0	9.03	-0.83	8.20	57.05	0.72

Table 3.48
Damage Stability, Departure Condition

			Intact Condition			*------Equilibrium Condition------- -----------After Damage-------------*					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv-ival?**
1	DPRT001A	1	5.463	6.640	4.652	0.0	2.432	50.00	20.21	4.664	Yes
2	DPRT002A	2	5.463	6.640	4.652	0.0	2.347	50.00	20.79	4.780	Yes
3	DPRT003A	3	5.463	6.640	4.652	0.0	1.683	50.00	14.21	3.204	Yes
4	DPRT004A	6	5.463	6.640	4.652	0.1P	1.891	49.88	14.92	----	Yes
5	DPRT005A	10	5.463	6.640	4.652	0.0	1.749	50.00	17.41	4.070	Yes
6	DPRT006A	13	5.463	6.640	4.652	1.8S	2.201	48.23	16.83	----	Yes
7	DPRT007A	15	5.463	6.640	4.652	0.0	2.171	50.00	19.47	4.442	Yes
8	DPRT008A	15,13	5.463	6.640	4.652	2.6S	1.798	47.42	14.97	----	Yes
9	*DPRT009A*	*3,4*	*5.463*	*6.640*	*4.652*	*0.5S*	*1.780*	*49.48*	*14.65*	----	*Yes*
10	*DPRT010A*	*6,7*	*5.463*	*6.640*	*4.652*	*0.4S*	*1.979*	*49.58*	*15.39*	----	*Yes*

Table 3.49
Damage Stability, Return Condition

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*Equilibrium Condition After Damage* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTRN001B	1	4.698	8.200	3.723	0.0	1.676	50.00	15.33	3.709	Yes
2	RTRN002B	2	4.698	8.200	3.723	0.0	1.731	50.00	15.90	3.724	Yes
3	RTRN003B	3	4.698	8.200	3.723	0.0	0.973	50.00	7.77	1.724	Yes
4	RTRN004B	6	4.698	8.200	3.723	0.1P	1.197	49.90	9.37	----	Yes
5	RTRN005B	10	4.698	8.200	3.723	0.0	1.203	50.00	12.30	2.827	Yes
6	RTRN006B	13	4.698	8.200	3.723	2.4S	1.513	47.55	11.76	----	Yes
7	RTRN007B	15	4.698	8.200	3.723	0.0	1.539	50.00	14.48	3.430	Yes
8	RTRN008B	15,13	4.698	8.200	3.723	3.8S	1.215	46.20	9.75	----	Yes
9	*RTRN009B*	*3,4*	*4.698*	*8.200*	*3.723*	*4.8S*	*1.061*	*45.17*	*6.35*	----	*Yes*
10	*RTRN010B*	*6,7*	*4.698*	*8.200*	*3.723*	*4.6S*	*1.233*	*45.35*	*7.20*	----	*Yes*

3.5 Passenger Cruise Vessel

3.5.1 180' Cruise Boat (112 passengers)

This vessel is unique in the study group because it has davit launched lifeboats. Its passenger complement relative to displacement is quite small and therefore produces low heeling arms which are nonetheless greater than those due to wind heel (0.14') and lifeboat launching loads (0.08'). All heeling arms are so small that the statutory minimum of GZ_{max} = 0.328' applies.

Since no deck arrangement plans were available, entire complement of 112 passengers was concentrated to one side at the rail. This is the most rigorous possible interpretation of the requirement and is still easily sustained.

Table 3.50
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure	796.0	16.98	0.00	16.98	123.22	0.28*
Return	739.2	17.57	0.00	17.57	123.22	0.30*

* Values are less than statutory minimum of 0.328'.

Table 3.51
Damage Stability, Departure Condition

Case No.	File	Damaged Compts	Intact Condition Mean draft (ft)	VCG (ft)	GMt (ft)	Equilibrium Condition After Damage Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	DPRT001A	1	7.509	16.980	5.660	0.0	1.923	37.56	24.28	5.475	Yes
2	DPRT002A	2	7.509	16.980	5.660	0.0	1.882	36.76	23.98	5.474	Yes
3	DPRT003A	3	7.509	16.980	5.660	0.0	1.685	35.59	21.99	5.150	Yes
4	DPRT004A	5	7.509	16.980	5.660	5.1P	1.361	29.08	13.82	----	Yes
5	DPRT005A	7	7.509	16.980	5.660	0.0	0.906	28.50	13.24	3.624	Yes
6	DPRT006A	8	7.509	16.980	5.660	0.0	1.212	31.87	16.94	4.189	Yes
7	DPRT007A	9	7.509	16.980	5.660	0.0	1.148	31.24	16.58	4.310	Yes
8	DPRT008A	10	7.509	16.980	5.660	0.0	1.510	34.44	19.42	4.356	Yes
9	DPRT009A	13	7.509	16.980	5.660	0.0	1.710	35.56	22.20	5.106	Yes
10	DPRT010A	14	7.509	16.980	5.660	0.0	1.908	37.13	24.14	5.436	Yes
11	DPRT011A	10,11	7.509	16.980	5.660	0.2P	1.525	34.24	19.42	----	Yes

Table 3.52
Damage Stability, Return Condition

Case No.	File	Damaged Compts	Intact Condition Mean draft (ft)	VCG (ft)	GMt (ft)	Equilibrium Condition After Damage Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	RTRN001A	1	7.102	17.570	5.756	0.0	1.954	37.33	24.62	5.543	Yes
2	RTRN002A	2	7.102	17.570	5.756	0.0	1.946	36.81	24.52	5.534	Yes
3	RTRN003A	3	7.102	17.570	5.756	0.0	1.781	35.63	22.75	5.193	Yes
4	RTRN004A	5	7.102	17.570	5.756	1.3S	1.572	33.32	19.06	----	Yes
5	RTRN005A	7	7.102	17.570	5.756	0.0	0.946	29.11	13.30	3.324	Yes
6	RTRN006A	8	7.102	17.570	5.756	0.0	1.288	32.08	17.24	4.027	Yes
7	RTRN007A	9	7.102	17.570	5.756	0.0	1.237	31.57	17.14	4.185	Yes
8	RTRN008A	10	7.102	17.570	5.756	0.0	1.557	34.34	19.74	4.359	Yes
9	RTRN009A	13	7.102	17.570	5.756	0.0	1.765	35.49	22.70	5.168	Yes
10	RTRN010A	14	7.102	17.570	5.756	0.0	1.936	36.93	24.45	5.514	Yes
11	RTRN011A	10,11	7.102	17.570	5.756	0.4S	.1.560	33.92	19.66	----	Yes

3.6 Ferries

3.6.1 84' Ferry (90 passengers)

This ferry runs a single cross-river route tethered to an underwater cable and powered by a "yawl boat" tied off to its side. The damage stability calculations do not account for these external forces, which would probably contribute to greater stability, especially in situations of applied heel. The 84' ferry passes all requirements in its single operating mode, here considered with trucks loaded on deck. One may observe that the low passenger capacity relative to displacement enables this vessel to pass in spite of its beamy and shallow form.

For passenger crowding, all are placed on the main deck rail.

Table 3.53
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Normal operating	85.7	5.84	0.00	5.84	78.56	1.05

Table 3.54
Damage Stability, Normal Operating Condition

			Intact Condition			------*Equilibrium Condition*------- -----------*After Damage*------------					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv-ival?**
1	OPER001A	1	1.825	5.840	28.962	0.0	4.518	50.00	75.33	27.096	Yes
2	OPER002A	2	1.825	5.840	28.962	0.0	3.968	50.00	67.03	25.713	Yes
3	OPER003A	3	1.825	5.840	28.962	0.0	3.070	50.00	53.13	24.269	Yes
4	OPER004A	4	1.825	5.840	28.962	0.0	3.426	50.00	58.95	24.287	Yes
5	OPER005A	5	1.825	5.840	28.962	0.0	3.150	50.00	54.48	24.387	Yes
6	OPER006A	6	1.825	5.840	28.962	0.0	3.969	50.00	67.05	25.713	Yes
7	OPER007A	7	1.825	5.840	28.962	0.0	4.518	50.00	75.33	27.096	Yes

3.6.2 175' Ferry (1600 passengers)

This ferry has many loading conditions with a variety of passenger/vehicle combinations. Two conditions are investigated: "A": 1600 passengers and no vehicles; and "B": 1220 passengers and 40 automobiles. All collision flooding cases are symmetric; cases 6, 9, and 12 are added grounding cases in which service tanks inboard of B/5 are involved. One compartment flooding applies except at the bow and stern.

The wide beam (39') and high passenger capacity make compliance with the passenger crowding requirement difficult. Two passenger muster arrangements were tried for each loading condition; all requirements except passenger crowding heel were passed in every case. The four conditions, "Departure" and "Return", A and B, represent a high load arrangement in which 1176 of 1600 passengers are distributed on the three upper decks. The ferry fails in every case to sustain the resulting heeling arm ("DPRT" cases are available separately upon request with detailed hydrostatic and damage stability results).

An alternate arrangement is difficult to develop from interpretation of the Coast Guard guidance letter. In this instance, high passenger capacity must be addressed, as well as some notion of what constitutes suitable egress. Configurations "A1" and "B1" account for fewer passengers by eliminating two upper evacuation decks (the first deck is completely enclosed and the third is probably too high) from the model and adding the main deck.; the main deck is the vehicle stowage deck, from which a 7.5' wide door may be accessed for escape. The second upper deck is otherwise the lowest deck appropriate for disembarkation and is therefore "crowded" to the maximum extent (372 passengers). 400 passengers are placed on the main deck for configuration A1 and 200 for B1 (deck filled with cars).

Table 3.55
Pre-damage Conditions

Condition	Δ (LT)	VCG_0 (ft)	GG_1 (ft)	VCG_1 (ft)	PAX heel (LT-ft)	GZ_{reqd} (ft)
Departure A	694.2	19.05	0.00	19.05	884.6	1.40
Return A	656.2	19.48	0.00	19.48	884.6	1.48
Departure A1	694.2	19.05	-0.24	18.81	620.61	1.02
Return A1	656.2	19.48	0.17	19.65	620.61	1.08
Departure B	729.1	18.88	0.00	18.88	884.6	1.34
Return B	689.3	19.28	0.00	19.28	884.6	1.41
Departure B1	729.1	18.88	0.00	18.88	458.56	0.76
Return B1	689.3	19.28	0.00	19.28	458.56	0.80

B1 passes all cases by narrow margins (results available separately upon request) while A1 fails in most cases (see Tables 3.56 and 3.57). Extensive subdivision modifications or substantial reduction of passenger capacity would be required to correct all cases of failure. Neither approach is likely to be economically feasible.

This vessel illustrates best the problem of determining what constitutes suitable evacuation arrangements in a flooding situation. No definition has been given to standards for location, capacity, and efficacy of egress from passenger muster areas, yet those considerations drive the critical damage stability requirement for every vessel. In the case of the 175' ferry, two radically different approaches were tried; no guidance is available by which to judge their relative merits.

Table 3.56
Damage Stability, Departure Condition (DPA1)

			Intact Condition			*——Equilibrium Condition—— ————After Damage————*					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv-ival?**
1	DPA1001A	1	8.383	18.810	4.184	0.0	1.386	34.89	17.16	4.213	Yes
2	DPA1002A	1,2	8.383	18.810	4.184	0.0	1.174	31.62	16.00	4.001	Yes
3	DPA1003A	2	8.383	18.810	4.184	0.0	1.243	33.05	16.34	4.099	Yes
4	DPA1004A	3	8.383	18.810	4.184	0.0	1.105	32.39	14.81	3.796	Yes
5	DPA1005A	4	8.383	18.810	4.184	0.0	**0.975**	30.96	13.35	3.498	No
6	*DPA1006A*	*4,5*	*8.383*	*18.810*	*4.184*	*0.5P*	***0.944***	*30.27*	***12.65***	----	*No*
7	DPA1007A	7	8.383	18.810	4.184	0.0	1.107	31.86	14.84	3.713	Yes
8	DPA1008A	8	8.383	18.810	4.184	0.0	1.089	31.69	14.43	3.520	Yes
9	*DPA1009A*	*9,8*	*8.383*	*18.810*	*4.184*	*0.0*	*1.141*	*31.95*	*15.16*	*3.446*	*Yes*
10	DPA1010A	10	8.383	18.810	4.184	0.0	**1.015**	30.68	13.64	3.176	No
11	DPA1011A	11	8.383	18.810	4.184	0.0	1.081	32.28	13.33	3.022	Yes
12	*DPA1012A*	*11,12*	*8.383*	*18.810*	*4.184*	*0.8P*	***1.000***	*30.76*	*11.97*	----	*No*
13	DPA1013A	14	8.383	18.810	4.184	0.0	1.155	32.56	14.05	3.087	Yes
14	DPA1014A	15	8.383	18.810	4.184	0.0	1.256	33.40	15.20	3.330	Yes

Table 3.57
Damage Stability, Return Condition (RTA1)

			Intact Condition			*------Equilibrium Condition------- -----------After Damage-------------*					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv- -ival?**
1	RTA1001A	1	8.129	19.480	3.852	0.0	1.210	33.48	14.99	3.725	Yes
2	RTA1002A	1,2	8.129	19.480	3.852	0.0	1.025	30.34	13.80	3.459	No
3	RTA1003A	2	8.129	19.480	3.852	0.0	1.082	31.65	14.12	3.444	Yes
4	RTA1004A	3	8.129	19.480	3.852	0.0	0.947	30.96	12.57	3.095	No
5	RTA1005A	4	8.129	19.480	3.852	0.0	0.824	29.62	11.14	2.853	No
6	*RTA1006A*	*4,5*	*8.129*	*19.480*	*3.852*	*0.2S*	*0.818*	*29.29*	*10.98*	----	*No*
7	RTA1007A	7	8.129	19.480	3.852	0.0	0.962	30.65	12.75	3.251	No
8	RTA1008A	8	8.129	19.480	3.852	0.0	0.945	30.54	12.37	3.084	No
9	*RTA1009A*	*9,8*	*8.129*	*19.480*	*3.852*	*0.0*	*0.958*	*30.44*	*12.55*	*3.131*	*No*
10	RTA1010A	10	8.129	19.480	3.852	0.0	**0.907**	29.86	11.90	2.755	No
11	RTA1011A	11	8.129	19.480	3.852	0.0	**0.952**	31.24	11.44	2.658	No
12	*RTA1012A*	*11,12*	*8.129*	*19.480*	*3.852*	*0.9S*	*0.952*	*30.23*	*11.02*	----	*No*
13	RTA1013A	14	8.129	19.480	3.852	0.0	1.037	31.61	12.29	2.724	No
14	RTA1014A	15	8.129	19.480	3.852	0.0	1.110	32.31	13.42	3.070	Yes

3.6.3 192' Ferry (3000/1000 passengers)

Two loading configurations are used: "A"- 3000 passengers and no automobiles; and "B"-1000 passengers and 60 automobiles. Departure conditions only were available from Coast Guard file.

Table 3.58
Pre-damage Conditions

Condition	**Δ (LT)**	**VCG_0 (ft)**	**GG_1 (ft)**	**VCG_1 (ft)**	**PAX heel (LT-ft)**	**GZ_{reqd} (ft)**
Departure A	1355.4	17.34	0.00	17.34	3889.29	3.00
Departure B	1415.7	16.47	0.00	16.47	1944.64	1.50

No deck plans were available for the 192' ferry. For passenger crowding heeling loads, it was assumed for configuration "A" that 2000 people are located B/10 from the side, a transverse lever of 26.4'. All 1000 passengers are likewise located for configuration "B". This is an extremely conservative interpretation of the crowding requirement.

The vessel passes all specified collision damage cases, but fails three of the seven added catastrophic grounding cases (14 through 20). The relatively high freeboard and low passenger to displacement ratio are favorable for achieving compliance.

Table 3.59
Damage Stability, Departure Condition A

			Intact Condition			***------Equilibrium Condition------ -----------After Damage------------***					
Case No.	**File**	**Damaged Compts**	**Mean draft (ft)**	**VCG (ft)**	**GMt (ft)**	**Heel (deg)**	**GZ max (ft)**	**Range (deg)**	**Area (ft-deg)**	**DAM. GMt (ft)**	**Surv- -ival?**
1	DPTA001A	1,2	6.380	17.340	74.445	0.5S	7.941	47.64	133.36	----	Yes
2	DPTA002A	1,2,3	6.380	17.340	74.445	0.7S	7.219	44.85	121.69	----	Yes
3	DPTA003A	2	6.380	17.340	74.445	0.4S	8.783	50.28	147.07	----	Yes
4	DPTA004A	6,2	6.380	17.340	74.445	1.0S	7.536	46.73	123.98	----	Yes
5	DPTA005A	6	6.380	17.340	74.445	0.4S	8.884	50.57	148.81	----	Yes
6	DPTA006A	6,9	6.380	17.340	74.445	0.9S	7.704	47.25	127.07	----	Yes
7	DPTA007A	9	6.380	17.340	74.445	0.4S	8.887	50.59	148.86	----	Yes
8	DPTA008A	9,11	6.380	17.340	74.445	1.6S	6.458	43.30	104.09	----	Yes
9	DPTA009A	11	6.380	17.340	74.445	1.0S	7.651	47.13	125.97	----	Yes
10	DPTA010A	11,13	6.380	17.340	74.445	1.7S	6.377	42.94	101.95	----	Yes
11	DPTA011A	13	6.380	17.340	74.445	0.5S	8.828	50.51	147.69	----	Yes
12	DPTA012A	13,15	6.380	17.340	74.445	0.7S	7.272	45.84	121.81	----	Yes
13	DPTA013A	15,16	6.380	17.340	74.445	0.0	7.705	46.86	133.06	59.83	Yes
14	*DPTA014A*	*1,2,3,4*	*6.380*	*17.340*	*74.445*	*0.6S*	*7.343*	*44.58*	*124.38*	----	*Yes*
15	*DPTA015A*	*2,3,4,6,7*	*6.380*	*17.340*	*74.445*	*0.8S*	*7.673*	*44.54*	*128.17*	----	*Yes*
16	*DPTA016A*	*6,7,9,10*	*6.380*	*17.340*	*74.445*	*1.2S*	*7.307*	*43.97*	*120.05*	----	*Yes*
17	*DPTA017A*	*9,10,11*	*6.380*	*17.340*	*74.445*	*2.2S*	*5.586*	*39.72*	*88.46*	----	*Yes*
18	*DPTA018A*	*9,10,11,12*	*6.380*	*17.340*	*74.445*	*4.0S*	***1.320***	*16.96*	*14.62*	----	*No*
19	*DPTA019A*	*11,12,13*	*6.380*	*17.340*	*74.445*	*3.2S*	***2.327***	*23.48*	*32.52*	----	*No*
20	*DPTA020A*	*12,13,15*	*6.380*	*17.340*	*74.445*	*4.4S*	***0.137***	*3.04*	*0.26*	----	*No*

Table 3.60
Damage Stability, Departure Condition B

Case No.	File	Damaged Compts	*Intact Condition* Mean draft (ft)	VCG (ft)	GMt (ft)	*Equilibrium Condition After Damage* Heel (deg)	GZ max (ft)	Range (deg)	Area (ft-deg)	DAM. GMt (ft)	Surv-ival?
1	DPTB001B	1,2	6.585	16.530	71.292	0.6S	7.566	48.05	127.87	----	Yes
2	DPTB002B	1,2,3	6.585	16.530	71.292	0.7S	6.815	44.94	115.39	----	Yes
3	DPTB003B	2	6.585	16.530	71.292	0.5S	8.423	50.90	142.04	----	Yes
4	DPTB004B	6,2	6.585	16.530	71.292	1.0S	7.203	47.20	119.17	----	Yes
5	DPTB005B	6	6.585	16.530	71.292	0.4S	8.524	51.20	143.76	----	Yes
6	DPTB006B	6,9	6.585	16.530	71.292	1.0S	7.352	47.74	122.05	----	Yes
7	DPTB007B	9	6.585	16.530	71.292	0.4S	8.524	51.20	143.75	----	Yes
8	DPTB008B	9,11	6.585	16.530	71.292	1.7S	6.120	43.54	99.01	----	Yes
9	DPTB009B	11	6.585	16.530	71.292	1.0S	7.296	47.56	120.75	----	Yes
10	DPTB010B	11,13	6.585	16.530	71.292	1.7S	6.044	43.12	96.87	----	Yes
11	DPTB011B	13	6.585	16.530	71.292	0.5S	8.474	51.09	142.57	----	Yes
12	DPTB012B	13,15	6.585	16.530	71.292	0.7S	6.850	45.91	115.31	----	Yes
13	DPTB013B	15,16	6.585	16.530	71.292	0.0	7.228	46.75	125.38	57.521	Yes
14	*DPTB014B*	*1,2,3,4*	*6.585*	*16.530*	*71.292*	*0.6S*	*6.890*	*44.64*	*117.34*	----	*Yes*
15	*DPTB015B*	*2,3,4,6,7*	*6.585*	*16.530*	*71.292*	*0.9S*	*7.187*	*44.67*	*120.59*	----	*Yes*
16	*DPTB016B*	*6,7,9,10*	*6.585*	*16.530*	*71.292*	*1.3S*	*6.817*	*44.09*	*112.69*	----	*Yes*
17	*DPTB017B*	*9,10,11*	*6.585*	*16.530*	*71.292*	*2.3S*	*5.195*	*39.60*	*82.52*	----	*Yes*
18	*DPTB018B*	*9,10,11,12*	*6.585*	*16.530*	*71.292*	*5.0S*	***0.559***	*11.35*	*4.21*	----	*No*
19	*DPTB019B*	*11,12,13*	*6.585*	*16.530*	*71.292*	*3.6S*	*1.570*	*19.58*	*19.81*	----	*Yes*
20	*DPTB020B*	*12,13,15*	*6.585*	*16.530*	*71.292*	*0.0*	***0.000***	***0.00***	***0.00***	*51.696*	*No*

3.7 Passenger Crowding Heel Angles

Neither SOLAS nor Coast Guard regulations address static heel in the damaged condition with passenger crowding. Large angles of heel can often result, especially for smaller vessels. Table 3.61 gives heel data drawn from Volume 2, including only collision cases where the vessels pass the new regulation. These extreme attitudes are a safety hazard in their own right and should be considered in design and certification calculations, as well as in data supplied to the master.

Table 3.61
Passenger Crowding Heel Angles

VESSEL	Average Heel Angle (degrees)	Maximum Heel Angle (degrees)
80’ fishing boat	11	16
59’ fishing boat	11	18
80' shuttle boat	5	8
105’ dinner boat	5	5
106’ dinner boat	7	8
200’ excursion boat	6	10
192’ excursion boat	5	6
183’ dinner boat	4	5
80’ paddle wheeler	5	8
198’ casino boat	5	7
228’ casino boat	4	5
274’ paddle wheeler	2	7
91’ crew boat A	12	17
91’ crew boat B	16	28
99’ crew boat	18	30
102’ crew boat	5	8
122’ crew boat	10	17
180’ cruise boat, w/ lifeboats	4	8
84’ ferry	2	2
175’ ferry	17	20
192’ ferry	3	5

4. ANALYSIS

A simple method assessing overall performance of the sample vessel group relative to three key requirements was devised. Three factors of "attained safety" are found, for GZ_{reqd} due to passenger crowding, positive damage stability range, and righting energy, expressed as follows:

- A_{GZ} = average GZ_{max}/GZ_{reqd}
- A_{range} = average range/15°
- A_{energy} = average righting energy/2.82 foot-degrees
- A_{total} = average of three above

Relevant collision cases per CFR damage extents only were used in the original departure and return conditions. For the A_{GZ} calculation, the low moment passenger crowding configurations were used when more than one was tried. The higher of two passenger capacities (3000 vice 1000) was used for the 192'ferry.

The analysis reflects a generally robust fleet with respect to the SOLAS amendments. It must however be emphasized that significant individual failure cases, which are subsumed in the composite numbers (nearly all of which are greater than 1.0), are a problem, particularly for the smaller boats. The results appear in Table 4.1, which illustrates the ease with which the positive range and righting energy requirements are sustained by contemporary boat designs. A relatively high range of A_{GZ} numbers shows a general capacity to sustain passenger crowding heel in spite of individual cases of failure. Lower numbers are found in those small boats failing the requirement.

A parametric analysis of the attained safety factors relative to basic hull particulars was executed on a spreadsheet model (Appendix B). The parameters chosen were ratios of primary hull dimensions and do not account for such influences as hull form coefficients, subdivision arrangements, and co-dependent effects among the parameters chosen; those trends observed are therefore quite uneven and have significant anomalies. Figures 4.1, 4.2, and 4.3 plot the A factors against those simple parameters for which trends were most apparent.

Figure 4.1 plots A_{GZ} against the ratio of passengers to displacement (LT) in the departure condition. The ratio describes the extent to which passenger capacity is maximized and trends the obvious proportional effect of the resulting heeling loads, tending downward with increasing A_{GZ}. The anomaly at the high end is the 105' dinner boat, whose relatively high C_b and flared shell contribute positively.

Figure 4.2 plots A_{range} against freeboard/depth (f/D) and depth/breadth (D/B), both of which trend unevenly upward with increasing A_{range}. The low f/D and D/B values at the high end correspond to the 84' ferry, which is beamy and shallow but with barge-like form and a very high C_b.

Figure 4.3 plots A_{energy} against length/depth (L/D). The barely discernible upward trend of L/D with increasing A_{energy} is as clear an inference as can be drawn from available data. All the vessels in the study, of whatever form, passed this requirement easily; finding influential parameters is not a critical outcome.

Table 4.1
Attained Safety Factors

VESSEL	A_{GZ}	A_{range}	A_{energy}	A_{total}
80' fishing boat	1.26	2.64	10.57	4.82
59' fishing boat	1.17	3.26	8.12	4.18
80' shuttle boat	1.14	2.63	13.00	5.59
105' dinner boat	6.36	3.04	19.83	9.74
106' dinner boat	1.59	2.17	14.65	6.14
200' excursion boat	3.90	2.62	18.71	8.41
183' dinner boat	2.79	1.85	7.09	3.91
192' excursion boat	4.44	2.32	11.97	6.24
80' paddle wheeler	1.69	1.47	4.56	2.57
198' casino boat	1.96	1.56	13.97	5.83
228' casino boat	2.46	1.94	18.91	7.77
274' paddle wheeler	6.31	2.10	26.21	11.54
91' crew boat A	1.52	3.08	4.57	3.06
91' crew boat B	1.39	3.31	5.01	3.24
100' crew boat	1.40	3.29	4.76	3.15
102' crew boat	2.47	3.31	11.37	5.72
122' crew boat	2.71	3.26	4.95	3.64
180' cruise boat	4.75	2.27	7.11	4.71
84' ferry	3.62	3.33	22.86	9.94
175' ferry, config. A1	0.98	2.09	4.72	2.60
192' ferry, config. A	2.60	3.15	45.97	17.24

Figure 4.1
Attained GZ Factor

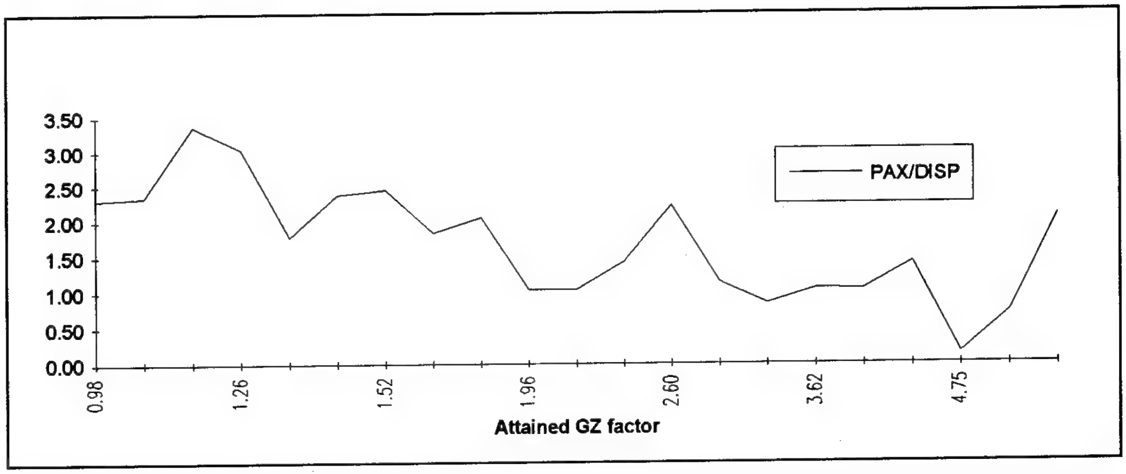


Figure 4.2
Attained Positive Righting Range Factor

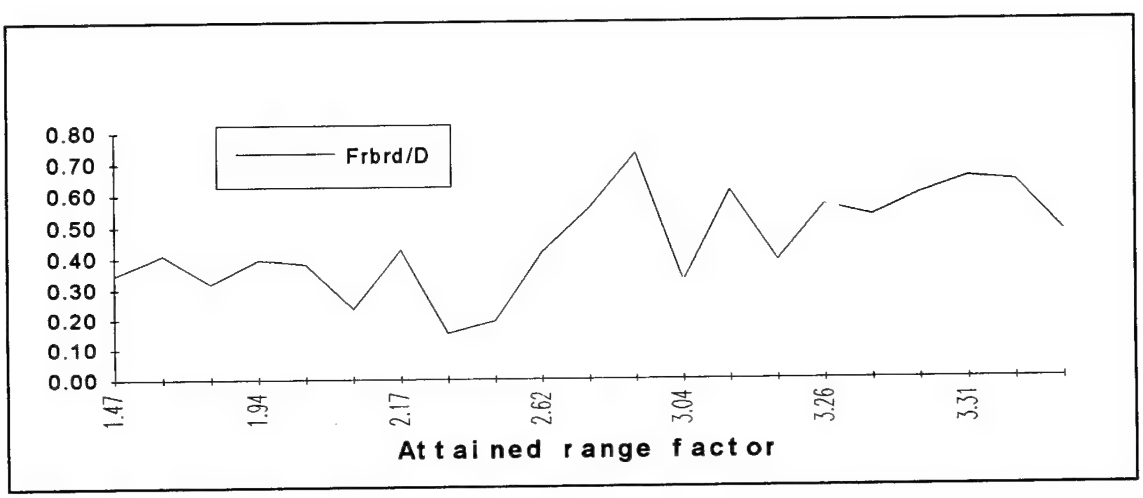
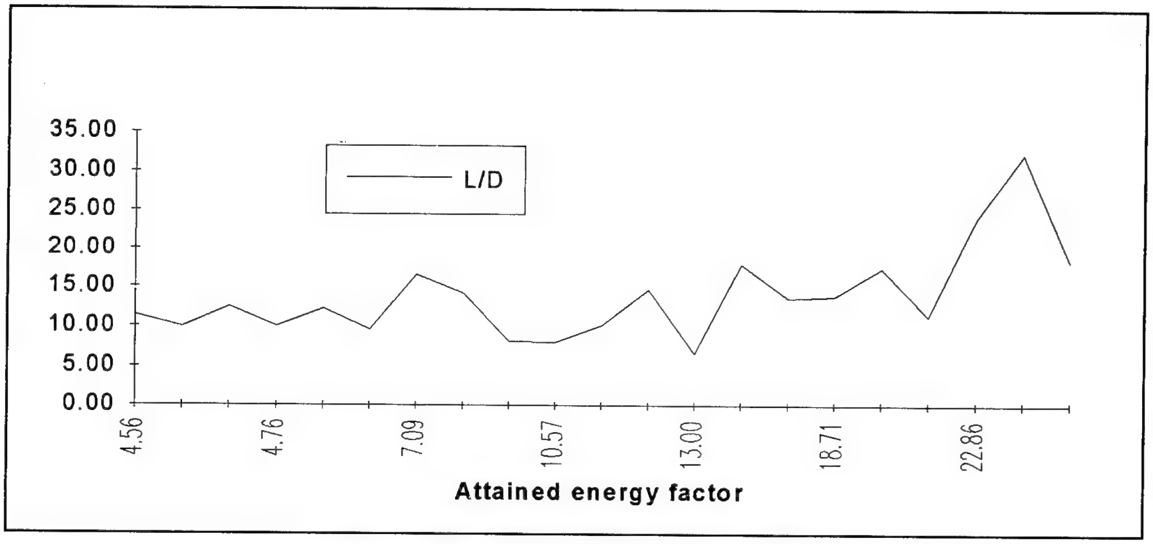


Figure 4.3
Attained Righting Energy Factor



5. *CONCLUSIONS AND RECOMMENDATIONS*

5.1 Summary

The vessel designs examined present a wide range of sizes, services, and passenger capacities. On the whole, they performed well relative to the new damage stability regulations (sixteen of twenty-one passed all requirements without design modifications); it appears that their designs, whether implicitly or by specific intent, go well beyond the minimum standards given by the pre-1992 CFR damage stability regulations. Most compliance problems occurred among the smaller vessels and arose almost exclusively because of the passenger crowding heel requirement, with the following trends noted:

- Shallow hulls with low freeboards often fail to sustain heeling arms and, in the single instance observed, lack the required positive stability range and energy.
- Vessels with high ratios of passengers to displacement, particularly the smaller vessels, are those which fail by the widest margins to sustain crowding heel moments.
- Beamy vessels with adequate freeboard yield robust GZ curves, but the beam also carries the drawback of high passenger crowding levers.

The requirements for positive range, righting energy, and downflooding (CFR, not SOLAS requirement) appear to address protection from dynamic forces such as rolling due to beam waves. The relation of these three requirements to sustaining passenger crowding heeling arms should not, however, be overlooked, as they can buffer against the possible dynamic effects of such weight shifts.

Downflooding protection was not explicitly addressed due to insufficient drawing data and software constraints. A stepwise approach based on operating areas similar to that used for the intact stability weather criterion may merit consideration. Downflooding protection must at least extend to areas submerged in the static, heeled positions resulting from specified heeling forces, especially passenger crowding. Heel angles due to passenger crowding moments generally vary inversely with vessel size and are common in the 10°-30° range for smaller vessels.

The new regulations thus appear to be reasonable, since they improve safety standards where enormous risks (passengers) are involved, while implying minimal impact on a representative group of new designs. The ability to sustain heeling moments due to environmental (wind) and human (crowding) factors is appropriate from the viewpoints of both safety and liability.

The "attained safety factors" developed in Section 4 indicate a generally strong intrinsic ability among the fleet, with notable exceptions, to sustain the new regulations. Required positive range and righting energy thresholds, particularly the latter, are easily achieved, excepting the 80' paddle wheeler. The attained righting arm factors tended towards lower values and, while the composites conceal individual failure cases, they are a good relative measure of overall performance. Several trends were developed from the analysis, notably the influence of passenger load relative to displacement.

The scope of design modifications implied by the failures of five vessels to comply varies widely. Relocation of a bulkhead or foaming of void spaces was shown to be beneficial in some instances, but passenger capacity reduction to reduce crowding moments was usually a matter of unreasonably large percentages. Those smaller vessels with high passenger capacities which fail passenger crowding can present grave difficulties as subdivision of machinery spaces or reduction of passengers by at least half is required to achieve compliance.

Several suggestions for improving the specificity of the language in 46 CFR 171 are made, notably with regard to the passenger crowding requirement. It was found that a vessel could pass or fail with arrangements resulting from different interpretations of the rule. With the lack of minimum muster and egress requirements, the criticality of this regulation may drive designers into undesirable deck arrangements aimed only at reducing heeling arms due to crowding. The standard could specify minimum egress widths at the rail and reasonable evacuation deck height restrictions, while allowing more flexibility in arranging mustered passengers to reduce heeling moments.

5.2 Compliance

Specific findings relative to as-designed compliance are the following:

- All but one of the vessels studied passed requirements for residual GZ for wind load, positive stability range, righting energy, and static heel and most passed by wide margins. Only the eighty foot paddle wheeler failed positive range and righting energy.
- The controlling criterion in every case is residual GZ for heeling moment induced by passenger crowding. It ranged from 2.1 to 10.8 times the corresponding wind heel moment (see Table 4.1). Four small boats (L<91') and the 198' casino boat failed, the latter for one case only, caused by an unusually long forward compartment.
- GZ_{reqd} for wind heel was less than the absolute minimum of 0.328' for 17 of 21 vessels.
- Displacement and freeboard substantially determine the vessel's ability to meet the new requirements, particularly passenger crowding. Low displacement craft carrying large numbers of passengers and subject to large heeling moments in muster situations will naturally have proportionally higher heeling arms to sustain. The 91' crew boats "A" and "B" are very similar hulls, yet only the latter fails, because of higher passenger loads.
- As regards passenger crowding heel, modeling of distribution has great influence on the ability to comply. The Coast Guard's guidance letter can result in favorable loading relative to conventional muster areas (maximum number of passengers "on the rails"); the difference in one case, the 228' long casino boat, meant compliance for all cases versus failure in a large number of cases. There is a lack of egress standards and ample room to devise various interpretations of the requirement, with various levels of resulting passenger safety.
- Passenger crowding heeling moments result in a wide range of heel angles, generally varying inversely with vessel displacement. Many of the smaller vessels had average heel angles in excess of 10^{o} and maxima of up to 30^{o} (see Table 3.61). Such extreme attitudes may be safety problems in their own right.
- The static damaged heel limit of 7^{o} was passed by every vessel. Most relevant damage cases are symmetric flooding; those few which are not generally involve small service tanks and result in very small heel angles.
- Heel due to davit lifeboat launching is largely irrelevant because very few "T" and "H" boats carry davits. Only one vessel in the study, the 180' cruise boat, was affected and it passed the requirement easily.
- The downflooding requirement (protection within 15^{o} of static equilibrium) is problematic, particularly for beamy, shallow riverboats. Tightness of doors and hatches was not clear from the drawings; nor were locations of vents and other possible ingress points indicated. Potential design modification requirements could include improved door/hatch/window tightness or relocation, and relocations of air ducts and pipe vents.
- The new regulations lack any requirements for minimum available muster space (apart from fire "refuge" areas). Designs with limited available outboard space gain a significant advantage in meeting what has proven the critical specification--passenger crowding. Overall impact on design and operation of the study vessels

Table 5.1
Heeling arms, §171.080(e)(4)

VESSEL	WIND HEEL Departure Heeling arm (ft)	WIND HEEL Return Heeling arm (ft)	CROWDING HEEL Departure Heeling arm (ft)	CROWDING HEEL Return Heeling arm (ft)
80' fishing boat	0.25	xxx	1.49	xxx
59' fishing boat	0.18	0.22	1.31	1.55
80' shuttle boat	0.16	0.18	0.61	0.65
105' dinner boat	0.18	0.18	1.96	2.02
106' dinner boat	0.11	0.11	1.17	1.19
200' excursion boat	0.17	0.18	0.35	0.37
192' excursion boat	0.25	0.25	0.98	1.00
183' dinner boat	0.10	xxx	0.43	xxx
80' paddle wheeler	0.12	0.14	0.16	0.18
198' casino boat	0.13	0.14	1.21	1.25
228' casino boat	0.15	0.15	1.03	1.05
274' paddle wheeler	0.16	0.16	0.58	0.60
75' crew boat	0.23	0.25	0.46	0.49
91' crew boat A	0.14	0.16	0.50	0.58
91' crew boat B	0.11	0.13	0.77	0.89
99' crew boat	0.23	0.25	0.75	0.83
102' crew boat	0.19	0.24	0.87	1.08
122' crew boat	0.12	0.17	0.43	0.59
180' cruise boat	0.14	0.15	0.15	0.17
84' ferry	0.01	xxx	0.92	xxx
175' ferry, config. A	0.15	0.16	1.27	1.35
175' ferry, config. B	0.14	0.15	1.21	1.28
175' ferry, config. A1	0.15	0.16	0.89	0.95
175' ferry, config. B1	0.14	0.15	0.63	0.67
192' ferry, config. A	0.08	xxx	2.87	xxx
192' ferry, config. B	0.08	xxx	1.37	xxx

from the regulations was minimal. Designers will have the additional burden of calculating specified heeling moments and finding the vessel's "V-lines" for consideration of downflooding points. Subdivision and damage stability are already addressed, as are the wind heel areas and moments. Operators will have to be cognizant of status of all downflooding points which may be exposed after a casualty and of specific passenger muster arrangements used to achieve compliance.

5.3 Remedial modifications for compliance

- The 198' casino boat was brought into compliance with the passenger heel requirement by relocating one forward bulkhead to get more uniform spacing. No reduction in passenger loading was necessary.
- The 80' fishing boat fails to meet passenger crowding by such a small margin, for one case only, that no specific modification is suggested. Some foaming of the affected space would solve the problem.
- Addition of a subdivision bulkhead was suggested for the 59' fishing boat in lieu of a severe passenger capacity reduction. The functions of the affected spaces are not available in the Coast Guard file; design impact is therefore uncertain.
- The 80' paddle wheeler, a high passenger capacity vessel, failed most extensively to comply with the new requirements. Remediation by draconian passenger reduction or addition of subdivision bulkheads is probably not feasible for this hull form.
- 91' crew boat B has robust characteristics for a small vessel, but cannot sustain very high passenger heeling moments. Additional subdivision of all affected spaces is not possible (machinery arrangements) and notional passenger reduction (55%)is probably unacceptable.
- The downflooding criterion as written can probably be met without major impact, except for river service boats. Most damage conditions on Subchapter T and H boats result in symmetric flooding and this requirement seems to be independent of conditions with imposed heeling moments (wind, passenger crowding). A general check of doors, windows, hatches, etc. for weathertightness (in accordance with Coast Guard letter guidance) would be required. Locations of air supplies and exhausts, pipe vents, and other openings must also be checked.

5.4 General comments on CFR §171.080

The following are observations on and recommended revisions for 46 CFR §171.080. Most deal with the passenger crowding heel requirement (para. (e)(4)(i and ii)) for which guidance is now limited to the CFR language and Coast Guard letter 16703/46 CFR 171.080(e) of July 20, 1993:

- There is a fundamental lack of definition of evacuation scenarios and of what may constitute acceptable muster areas. The Coast Guard letter simply states that the most adverse heeling moment possible is to be imposed by using all available areas

on "muster deck(s)", where "passengers go to assemble and depart the vessel in the case of a flooding casualty". While these terms are not defined, the letter pointedly separates them from the fire egress specifications defined elsewhere in the CFR. For the vast majority of vessels affected by these regulations, the conventional notion of a lifeboat deck with muster areas does not apply. Life preservers are "distributed through the upper part of the vessel in protected places convenient to the passengers" (46 CFR §180.25-10); passenger movements are therefore not easily anticipated.

- Crowding to one side of the vessel is most often not the critical mode as anticipated by SOLAS for lifeboat launching scenarios on ocean-going passenger ships, particularly since most flooding casualties in the "T" and "H" fleets are symmetric.
- An alternative to consider is a standard which emphasizes adequate muster areas and access to the deck edge at a reasonable height above the waterline, while allowing more flexibility in the design of access to and location of passenger muster areas to lower heeling moments. Otherwise, designers may be tempted to arrange decks to minimize heeling moments and in so doing may actually compromise safety. The muster areas should be designed to accommodate some degree of off-center loading, as it is entirely conceivable that **passengers will have to crowd to one side of the boat** under some flooding casualty circumstances. The "bulkhead" or main deck is a logical evacuation point; a notional egress standard would be two doors or rail openings on each side. Designating the lower deck has the added advantage of lowering VCG due to passenger movement.
- The wording in §171.080(e)(4) varies from that of SOLAS 1990, i.e. "Each vessel must have a maximum righting arm within 15° of the angle of equilibrium..." and then describes the various heeling scenarios to be met, whereas SOLAS does not limit the angle of maximum GZ. This difference was critical for two of the vessels studied. Coast Guard Headquarters indicates that this distinction was not intended and that the language in the rule needs to be reviewed (the August 10, 1994 revision has harmonized with SOLAS).
- Neither SOLAS nor the Coast Guard regulation limits heel angle in the damaged condition with passenger crowding. The large resulting angles found herein may constitute an unanticipated hazard.
- The passenger heeling requirement as written in both SOLAS and the CFR has an intrinsic conservative element beyond the required safety margin of 0.13 feet: it does not allow for the cosine correction, which diminishes GZ reductions through larger angles of heel, classically applied to instances of weight shift, wind loading, etc.
- The new schedule of coefficients reducing required GZ for non-exposed service areas appears to significantly erode the intent of the passenger crowding aspect of the SOLAS amendments. The coefficients of 0.75 and 0.50 seem to imply that passengers weigh less in those waters or will be less inclined to move to the side than in exposed waters.
- The downflooding requirement is probably too stringent for vessels operating in protected or partially protected waters. It could be restructured in incremental steps

tied to operating service areas (similar to the weather criterion) provided the intent of all the other SOLAS amendments is met. That is: 1) downflooding protection must always be provided to account for static heel due to specified passenger crowding and/or wind loads; and 2) the righting energy requirement must be satisfied before a downflooding angle is reached. The revised rules of August 10, 1994 have done so.

- Damage extents are defined only for collisions (Table 171.080(a)). While some international codes now consider grounding scenarios as well, no corresponding revision appears in the CFR.
- No provision is yet made for assuring that pertinent damage stability information relative to applied heeling moments is in the master's hands.

APPENDIX A

WIND AND PASSENGER HEELING MOMENT SPREADSHEETS

TABLE A-1

PASSENGER CROWDING MOMENT

VESSEL	Passenger Capacity	Area 1 (A1) (ft^2)	#passengrs (PAX1)	Lever 1 (L1 (ft)	A2	PAX2	L2	A3	PAX3	L3	A4	PAX4	L4	Heeling moment (LT-ft)	Crowded PAX total	Departur displacem (LT)	Heeling arm (ft)	Return displacemt (LT)	Heeling arm (ft)
80' fishing boat	149	130	48	6.46	272	101	6.72		0			0		73.05	149	49.0	1.49	xxx	xxx
59' fishing boat	149	48	18	4.7	155	58	8.2	43	16	6.82		0		49.01	91	44.3	1.11	38.2	1.28
80' shuttle boat	200	353	131	5.37		0			0			0		51.91	131	85.3	0.61	79.4	0.65
105' dinner boat	600	252	94	9	252	94	9		0			0		124.21	187	288.0	0.43	279.0	0.45
105' dnnr bt config.#	600	252	94	9	252	94	9	1111	413	8.5		0		382.80	600	288.0	1.33	279.0	1.37
106' dinner boat	550	1071	398	8.97	249	93	8.10	155	58	7.90		0		351.83	548	299.5	1.17	295.3	1.19
200' excursion boat	800	268	100	10.47	219	81	8.93	392	146	13.25		0		272.62	327	770.5	0.35	737.7	0.37
192' excursion boat	600	266	99	8.38	420	156	8.63	827	307	8.56		0		354.14	562	422.1	0.84	414.5	0.85
183' dinner boat	600	863	321	7.52	315	117	15.00		0			0		307.10	438	714.0	0.43	xxx	xxx
80' paddle wheeler	500	186	69	7.62	348	129	6					0		95.99	199	243.8	0.39	219.7	0.44
198' casino boat	1900	4080	1517	15.00	480	178	19.00	192	71	28.00	360	134	15.00	2220.67	1900	1837.0	1.21	1777.0	1.25
228' casino boat	2500	800	297	33.32	440	164	23.00	930	346	15.50	2604	968	15.00	2471.36	1775	2409.0	1.03	2346.0	1.05
274' paddle wheeler	1200	600	223	15.00	700	260	15.00	280	104	28.00	540	201	15.00	970.46	788	1674.2	0.58	1606.3	0.60
91' crew boat A	250	156	58	9	108	40	5.38	-17.5	-7	6.6		0		51.19	92	102.1	0.50	88.2	0.58
91' crew boat B	149	270	100	5.00	60	22	9.75	34	13	8.80	6	7	6.50	64.29	142	83.7	0.77	72.4	0.89
91' crewB, PAX redc	68	183	68	5.00	0	0	0.00	0	0	0.00	0	0	0.00	25.06	68	83.7	0.30	72.4	0.35
100' crew boat	185	202	75	8.50	65	24	4.00	56	21	2.67		0		58.23	120	77.7	0.75	70.3	0.83
102' crew boat	150	195	72	5.75	210	78	10.5		0			0		91.08	151	105.1	0.87	84.5	1.08
122' crew boat	149	318	118	4.5	21	8	3	45	17	9.4	18	7	9.25	57.05	149	131.2	0.43	96.0	0.59
180' cruise boat	112	300	112	15		0			0			0		123.22	112	796.1	0.15	739.0	0.17
84' ferry	90	245	91	11.71		0			0			0		78.56	91	85.7	0.92	xxx	xxx
175' ferry, config. A	1600	3164	1176	10.21		0			0			0		884.60	1176	694.2	1.27	656.2	1.35
175' ferry, config. A1	1600	1076	400	11	268	100	9	92	34	8	640	238	12	620.61	772	694.2	0.89	656.2	0.95
175' ferry, config. B	1220	3164	1176	10.21		0			0			0		884.60	1176	729.1	1.21	689.3	1.28
175' ferry, config. B1	1220	268	100	9	92	34	8	640	238	12	538	200	11	458.56	572	729.1	0.63	689.3	0.67
192' ferry, config. A	3000	5380	2000	26.4		0			0			0		3889.29	2000	1355.4	2.87	xxx	xxx
192' ferry, config. B	1000	2690	1000	26.4		0			0			0		1944.64	1000	1415.7	1.37	xxx	xxx

NOTES:

1. Available deck areas are A1, A2, A3, etc. and are divided by 2.69ft^2/passenger to yield PAX1, PAX2, etc. Transverse levers are L1, L2, etc.
2. Total muster capacity is given as "Crowded PAX total".
3. Add 0.13' to heeling arm to get required GZ.

TABLE A-2
WIND HEEL MOMENT

VESSEL	Intact draft	A1 (ft^2)	L1 (ft)	A2	L2	A3	L3	A4	L4	A5	L5	A6	L6	A7	L7	A8	L8	WIND HEEL (LT-ft)	Departure displacement (LT)	Heeling arm (ft)	Return displacement (LT)	Heeling arm (ft)
80' fishing boat	2.50'	87	8.25	699	5.95	32	7.97	262	14.25	70	20.25	23	23.25	11	27			12.5	49.0	0.25	xxx	xxx
59' fishing boat	3.17'	768	8															6.9	37.5	0.18	31.6	0.22
80' shuttle boat	4.89'	597	6.13	476	14.00	86	20.00	16	26.00									14.0	85.3	0.16	79.4	0.18
105' dinner boat	6.29'	376	4.75	990	11	1182	21.5	210	29.5	46	33.5							51.3	288.0	0.18	279.0	0.18
106' dinner boat	4.29'	1042	8.00	738	18.50	104	27.35	96	5.25	245	10.13	50	26.25					32.6	299.5	0.11	295.3	0.11
208' excursion boat	8.39'	3054	14.50	313	18.25	236	14.02	923	28.00	816	35.25	123	41.85	42	40.45	26	46.25	129.9	770.5	0.17	737.7	0.18
192' excursion boat	8.39'	4318	18.54															89.7	362.7	0.25	355.1	0.25
183' dinner boat	7.50'	2239	6.2	1300	16.6	200	27	561	25	145	36.5	80	21.8	140	33			74.6	714.0	0.10		#DIV/0!
60' paddle wheeler	4.57'	882	8.25	526	18.25	186	26.25	128	34.25	28	33							30.3	243.8	0.12	218.5	0.14
198' casino boat	6.47'	5520	18.25	340	8.25	406	10.50	1659	38.50	473	49.13	196	61.25	124	69.75			241.6	1837.0	0.13	1777.0	0.14
228' casino boat	7.83'	8814	24.16	2090	38.00	220	44.50	96	50.50	112	47.9							350.0	2409.0	0.15	2346.0	0.15
274' paddle wheeler	6.50'	10294	23.04	-469	3.25													264.1	1674.2	0.16	1606.3	0.16
91' crew boat A	3.58'	1304	9.32	85	2.25													13.8	102.1	0.14	88.2	0.16
91' crew boat B	3.31'	564	4.65	291	14.15	131	13.4											9.5	83.7	0.11	72.4	0.13
100' crew boat	3.61'	736	9.55	355	12.4	170	15.05	70	16.55	25	20.8							17.6	77.7	0.23	70.3	0.25
101' crew boat	3.61'	133	6.13	850	9.25	349	12.6	99	17.9	247	13.9							20.5	105.1	0.19	84.5	0.24
122' crew boat	4.69'	1440	10.07															16.2	131.2	0.12	96.0	0.17
180' cruise boat	10.77'	1710	9.89	1232	18.38	1208	26.38	326	34.38	140	35.38	161	41.88	109	17.14	13	12.1	108.0	796.1	0.14	739.0	0.15
84' ferry	1.82'	64	7.78	173	1.77	28	2.5	53	4.58									1.3	85.7	0.01	xxx	xxx
175' ferry, config. A	8.38'	2864	12.5	944	24.5	390	35	468	31.5	132	39							103.6	694.2	0.15	656.2	0.16
175' ferry, config. B	8.64'	2864	12.5	944	24.5	390	35	468	31.5	132	39							103.6	729.1	0.14	689.3	0.15
192' ferry, config. A	6.40'	5025	19.37															109.1	1355.4	0.08	xxx	xxx
192' ferry, config. B	6.60'	4930	19.37															107.0	1415.7	0.08	xxx	xxx

APPENDIX B

DETAILED HYDROSTATIC AND

DAMAGE STABILITY DATA

(AVAILABLE SEPARATELY AS VOLUME 2 OF THE REPORT)

APPENDIX C

ATTAINED SAFETY FACTOR SPREADSHEETS

Figure C-1

Sample Attained Safety Factor Calculations

106' dinner boat

	DEPARTURE				RETURN		
	GZ max (ft)	range (deg)	energy (ft-deg)		GZ max (ft)	range (deg)	energy (ft-deg)
Case 1	2.88	37.54	63.04	Case 1	2.86	36.84	61.34
Case 2	2.42	35.07	50.77	Case 2	2.41	34.45	49.50
Case 3	2.11	32.38	41.67	Case 3	2.11	31.88	40.87
Case 4	1.92	31.76	37.28	Case 4	1.91	31.24	36.41
Case 5	2.09	33.00	41.61	Case 5	2.09	32.42	40.58
Case 6	1.77	30.58	33.02	Case 6	1.76	30.11	32.36
Case 7	1.972	32.21	38.61	Case 7	1.97	31.7	37.82
Case 8	1.721	30.36	32.29	Case 8	1.723	29.94	31.81
Case 9	1.95	32.09	37.77	Case 9	1.946	31.6	37.02
Average	1.61	2.19	14.82		1.58	2.15	14.49

A (GZ)	A (RANGE)
1.59	2.17
A (ENERGY)	**A (TOTAL)**
14.65	6.14

180' cruise boat

	DEPARTURE				RETURN		
	GZ max (ft)	range (deg)	energy (ft-deg)		GZ max (ft)	range (deg)	energy (ft-deg)
Case 1	1.92	37.56	24.28	Case 1	1.95	37.33	24.62
Case 2	1.88	36.76	23.98	Case 2	1.95	36.81	24.52
Case 3	1.69	35.59	21.99	Case 3	1.78	35.63	22.75
Case 4	1.36	29.08	13.82	Case 4	1.57	33.32	19.06
Case 5	0.91	28.50	13.24	Case 5	0.95	29.11	13.30
Case 6	1.21	31.87	16.94	Case 6	1.29	32.08	17.24
Case 7	1.148	31.24	16.58	Case 7	1.237	31.57	17.14
Case 8	1.51	34.44	19.42	Case 8	1.557	34.34	19.74
Case 9	1.71	35.56	22.2	Case 9	1.765	35.49	22.7
Case 10	1.908	37.13	24.14	Case 10	1.936	36.93	24.45
Case 11	1.53	34.24	19.42	Case 11	1.56	33.92	19.66
Average	4.65	2.25	6.96		4.86	2.28	7.26

A (GZ)	A (RANGE)
4.75	2.27
A (ENERGY)	**A (TOTAL)**
7.11	4.71

Table C-1

Attained Safety Factors and Hull Parameters

	A (GZ)	A (RANGE)	A (ENERGY)	A (TOTAL)	PAX/DISP	Frbrd/D	D/B	L/B	L/D	PAX	DISP. (LT)	Lpp (feet)	B (feet)	D (feet)	Draft (feet)	Freeboard (feet)
80' fishing boat	1.26	2.64	10.57	4.82	3.04	0.73	0.38	3.08	8.04	149	49.0	74.00	24.00	9.20	2.50	6.70
59' fishing boat	1.17	3.26	8.12	4.18	3.36	0.57	0.37	2.95	8.08	149	44.3	59.00	20.00	7.30	3.17	4.13
80' shuttle boat	1.14	2.63	13.00	5.59	2.34	0.56	0.46	3.04	6.64	200	85.3	73.00	24.00	11.00	4.89	6.11
105' dinner boat	6.36	3.04	19.83	9.74	2.08	0.32	0.24	2.69	11.29	600	288.0	105.00	39.00	9.30	6.29	3.01
106' dinner boat	1.59	2.17	14.65	6.14	1.84	0.43	0.23	3.09	13.60	550	299.5	102.00	33.00	7.50	4.29	3.21
200' excursion boat	3.90	2.62	18.71	8.41	1.04	0.42	0.39	5.41	13.89	800	770.5	200.00	37.00	14.40	8.39	6.01
183' dinner boat	2.79	1.85	7.09	3.91	0.84	0.32	0.27	4.46	16.64	600	714.0	183.00	41.00	11.00	7.50	3.50
192' excursion boat	4.44	2.32	11.97	6.24	1.42	0.19	0.30	4.37	14.71	600	422.1	153.00	35.00	10.40	8.39	2.01
80' paddle wheeler	1.69	1.47	4.56	2.57	2.05	0.35	0.22	2.50	11.43	500	243.8	80.00	32.00	7.00	4.57	2.43
198' casino boat	1.96	1.56	13.97	5.83	1.03	0.41	0.18	3.30	18.00	1900	1837.0	198.00	60.00	11.00	6.47	4.53
228' casino boat	2.46	1.94	18.91	7.77	1.04	0.40	0.22	3.80	17.54	2500	2409.0	228.00	60.00	13.00	7.85	5.15
274' paddle wheeler	6.31	2.10	26.21	11.54	0.72	0.24	0.14	4.42	32.24	1200	1674.2	274.00	62.00	8.50	6.50	2.00
91' crew boat A	1.52	3.08	4.57	3.06	2.45	0.61	0.40	3.96	9.89	250	102.1	91.00	23.00	9.20	3.58	5.62
91' crew boat B	1.39	3.31	5.01	3.24	1.78	0.65	0.43	4.14	9.58	149	83.7	91.00	22.00	9.50	3.31	6.19
100' crew boat	1.40	3.29	4.76	3.15	2.38	0.60	0.50	5.00	10.00	185	77.7	90.00	18.00	9.00	3.61	5.39
102' crew boat	2.47	3.31	11.37	5.72	1.43	0.64	0.40	4.08	10.20	150	105.1	102.00	25.00	10.00	3.61	6.39
122' crew boat	2.71	3.26	4.95	3.64	1.14	0.53	0.48	5.81	12.20	149	131.2	122.00	21.00	10.00	4.69	5.31
180' cruise boat	4.75	2.27	7.11	4.71	0.14	0.15	0.32	4.50	14.17	112	796.1	180.00	40.00	12.70	10.77	1.93
84' ferry	3.62	3.33	22.86	9.94	1.05	0.48	0.13	3.11	24.00	90	85.7	84.00	27.00	3.50	1.82	1.68
175' ferry, config. A1	0.98	2.09	4.72	2.60	2.30	0.38	0.36	4.49	12.50	1600	694.2	175.00	39.00	14.00	8.64	5.36
192' ferry, config. A	2.60	3.15	45.97	17.24	2.21	0.39	0.16	2.91	18.29	3000	1355.4	192.00	66.00	10.50	6.40	4.10

APPENDIX D

SOLAS 1990 AMENDMENTS AND 1992 U.S. 46 CFR 171 EXCERPTS

equilibrium to the smaller of the following angles:

(i) The angle at which progressive flooding occurs; or

(ii) 22 degrees from the upright in the case of one compartment flooding or 27 degrees from the upright in the case of two compartment flooding.

(4) Each vessel must have a maximum righting arm within 15 degrees of the angle of equilibrium of at least 0.13 feet (0.04 meters) greater than each of the following heeling arms, but in no case less than 0.33 feet (0.10 meters):

(i) Passenger heeling moment divided by vessel displacement where the heeling moment is calculated assuming:

(A) Each passenger weighs 165 pounds (75 kilograms);

(B) Each passenger occupies 2.69 square feet (0.25 square meters) of deck area; and

(C) All passengers are distributed on available deck areas towards one side of the vessel on the decks where muster stations are located and in such a way that they produce the most adverse heeling moment.

(ii) Asymmetric passenger escape routes heeling moment divided by vessel displacement if the vessel has asymmetric passenger escape routes where the heeling moment is calculated assuming:

(A) Each passenger weighs 165 pounds (75 kilograms);

(B) Each passenger occupies 2.69 square feet (0.25 square meters) of deck area; and

(C) All passengers are distributed on available deck areas in a manner that accounts for the use of any asymmetric passenger escape routes to get to the decks where muster or embarkation stations are located and in such a way that they produce the most adverse heeling moment.

(iii) Launching of survival craft heeling moment divided by vessel displacement where the heeling moment is calculated assuming:

(A) All survival craft, including davit-launched liferafts and rescue boats, fitted on the side to which the vessel heels after sustained damage are swung out if necessary, fully loaded and ready for lowering;

(B) Persons not in the survival craft that are swung out and ready for lowering are centered about the center line so that they do not provide additional heeling or righting moments; and

(C) Survival craft on the side of the vessel opposite to which the vessel heels remain stowed.

(iv) Wind pressure heeling moment divided by vessel displacement where the heeling moment is calculated assuming:

(A) A wind pressure of 2.51 pounds per square foot (120 Newtons per square meter);

(B) The wind acts on an area equal to the projected lateral area of the vessel above the waterline corresponding to the intact condition; and

(C) The wind lever arm is the vertical distance from a point at one-half the mean draft, or the center of area below the waterline, to the center of the lateral area.

(5) Each vessel must have an angle of equilibrium that does not exceed the following:

(i) 7 degrees for one compartment flooding; or

(ii) 12 degrees for two compartment flooding.

(6) The margin line of the vessel must not be submerged in the equilibrium condition.

(7) Each vessel must have a maximum angle of equilibrium that does not exceed 15 degrees during each earlier stage of flooding.

(8) Each vessel must have a maximum righting arm of at least 0.16 feet (0.05 meters) and positive righting arms for a range of at least 7 degrees during each earlier stage of flooding. Only one breach in the hull and only one free surface need be assumed when meeting the requirements of this paragraph.

(f) *Equalization.* (1) Equalization systems on vessels of 150 gross tons or more in ocean service must meet the following:

(i) Equalization must be automatic except that the Commanding Officer, Marine Safety Center may approve other means of equalization if—

(A) It is impracticable to make equalization automatic; and

(B) Controls to cross-flooding equipment are located above the bulkhead deck.

(ii) Equalization must be fully accomplished within 15 minutes after damage occurs.

(2) Equalization on vessels under 150 gross tons in ocean service and on all vessels in other than ocean service must meet the follmwing:

(i) Equalization must not depend on the operation of valves.

(ii) Equalization must be fully accomplished within 15 minutes after damage occurs.

(3) The estimated maximum angle mf heel before equalization must be approved by the Commanding Officer, Marine Safety Center.

TABLE 171.080(a)—EXTENT AND CHARACTER OF DAMAGE

Vessel designator [1]	Longitudinal penetration [2]	Transverse penetration [3, 4]	Vertical penetration	Character of Damage
Z	10 feet (3 meters) plus).03L or 35 feet (10.7 meters) whichever is less.[5]	B/5	from the baseline upward without limit.	Assumes no damage to any main transverse watertight bulkhead.
Y	10 feet (3 meters) plus)0.03L or 35 feet (10.7 meters) whichever is less.	B/5	From the baseline upward without limit.	Assumes damage to no more than one main transverse watertight bulkhead.
X	10 feet (3 meters) plus)0.03L or 35 feet (10.7 meters whichever is less.	B/5	from the baseline upward without limit.	Assumes damage to no more than one main transverse watertight bulkhead.
	20 feet (6.1 meters) plus 0.04L.	B/5	From the top of the double bottom upward without limit.	Assumes damage to no more than one main transverse watertight bulkhead.
W	20 feet (6.1 meters) plus 0.04L.	B/5	From the baseline upward without limit.	Assumes damage to at least two main transverse watertight bulkheads.

([1]) W,X,Y, and Z are determined from Table 171.080(b).
([2]) L=LBP of the vessel in feet (meters).
([3]) B=the beam of the vessel in feet (meters) measured at or below the deepest subdivision load line as defined in 171.010(a) except that, when doing calculations for a vessel that operates only on inland waters or a ferry vessel, B may be taken as the mean of the maximum beam on the bulkhead deck and the maximum beam at the deepest subdivision load line.
([4]) The transverse penetration is applied inboard from the side of the vessel, at right angles to the centerline, at the level of the deepest subdivision load line.
([5]) .1L or 6 feet (1.8 meters) whichever is greater for vessels described in § 171.070(e)(2).

TABLE 171.080(b)

Vessel category	Vessel designator
Vessels with type I subdivision and a factor of subdivision as determined from § 171.065 (a) or (b) of 0.33 or less.	W.
Vessels with type I subdivision and a factor of subdivision as determined from § 171.065 (a) or (b) greater than 0.33 and less than or equal to 0.50.	X.
Vessels with Type II subdivision that are required to meet a two compartment standard of flooding.	Y.
All other vessels	Z.

TABLE 171.080(c)—PERMEABILITY

Spaces and tanks	Permeability (percent
Cargo, coal, stores	60.
Accommodations	95.
Machinery	85.
Tanks	0 or 95.[1]

[1] Whichever value results in the more disabling condition.

[CGD 79-023, 48 FR 51017, Nov. 4, 1983, as amended by CGD 88-070, 53 FR 34537, Sept. 7, 1988; CGD 89-037, 57 FR 41826, Sept. 11, 1992]

EFFECTIVE DATE NOTE: At 57 FR 41826, Sept. 11, 1992, § 171.080 was amended by revising the introductory text of paragraph (d), by redesignating paragraph (e) as paragraph (f), and by adding a new paragraph (e), effective December 10, 1992. For the convenience of the user, the superseded text appears as follows:

§ 171.080 Damage stability standards for vessels with Type I or Type II subdivision.

* * * * *

(d) *Damage survival.* A vessel is presumed to survive assumed damage if it meets the

permissible length otherwise required for such compartment. In such a case the volume of effective buoyancy assumed on the undamaged side shall not be greater than that assumed on the damaged side.

9 Where the required factor of subdivision is 0.50 or less, the combined length of any two adjacent compartments shall not exceed the floodable length.

Regulation 8

*Stability of passenger ships in damaged condition**

(Paragraphs 2.3, 2.4, 5 and 6.2 apply to passenger ships constructed on or after 29 April 1990 and paragraphs 7.2, 7.3 and 7.4 apply to all passenger ships)

1.1 Sufficient intact stability shall be provided in all service conditions so as to enable the ship to withstand the final stage of flooding of any one main compartment which is required to be within the floodable length.

1.2 Where two adjacent main compartments are separated by a bulkhead which is stepped under the conditions of regulation 7.5.1 the intact stability shall be adequate to withstand the flooding of those two adjacent main compartments.

1.3 Where the required factor of subdivision is 0.50 or less but more than 0.33 intact stability shall be adequate to withstand the flooding of any two adjacent main compartments.

1.4 Where the required factor of subdivision is 0.33 or less the intact stability shall be adequate to withstand the flooding of any three adjacent main compartments.

2.1 The requirements of paragraph 1 shall be determined by calculations which are in accordance with paragraphs 3, 4 and 6 and which take into consideration the proportions and design characteristics of the ship and the arrangement and configuration of the damaged compartments. In making these calculations the ship is to be assumed in the worst anticipated service condition as regards stability.

2.2 Where it is proposed to fit decks, inner skins or longitudinal bulkheads of sufficient tightness to seriously restrict the flow of water, the Administration shall be satisfied that proper consideration is given to such restrictions in the calculations.

* Refer to MSC/Circ.541 (as may be revised): Guidance notes on the integrity of flooding boundaries above the bulkhead deck of passenger ships for proper application of regulations II-1/8 and 20, paragraph 1, of SOLAS 1974, as amended.

2.3 The stability required in the final condition after damage, and after equalization where provided, shall be determined as follows:

2.3.1 The positive residual righting lever curve shall have a minimum range of 15° beyond the angle of equilibrium.

2.3.2 The area under the righting lever curve shall be at least 0.015 metre-radians, measured from the angle of equilibrium to the lesser of:

- **.1** the angle at which progressive flooding occurs;
- **.2** 22° (measured from the upright) in the case of one-compartment flooding, or 27° (measured from the upright) in the case of the simultaneous flooding of two or more adjacent compartments.

2.3.3 A residual righting lever is to be obtained within the range specified in 2.3.1, taking into account the greatest of the following heeling moments:

- **.1** the crowding of all passengers towards one side;
- **.2** the launching of all fully loaded davit-launched survival craft on one side;
- **.3** due to wind pressure;

as calculated by the formula:

$$GZ \text{ (in metres)} = \frac{\text{heeling moment}}{\text{displacement}} + 0.04$$

However, in no case is this righting lever to be less than 0.10 m.

2.3.4 For the purpose of calculating the heeling moments in paragraph 2.3.3, the following assumptions shall be made:

- **.1** Moments due to crowding of passengers:
  - **.1.1** four persons per square metre;
  - **.1.2** a mass of 75 kg for each passenger;
  - **.1.3** passengers shall be distributed on available deck areas towards one side of the ship on the decks where muster stations are located and in such a way that they produce the most adverse heeling moment.
- **.2** Moments due to launching of all fully loaded davit-launched survival craft on one side:

.2.1 all lifeboats and rescue boats fitted on the side to which the ship has heeled after having sustained damage shall be assumed to be swung out fully loaded and ready for lowering;

.2.2 for lifeboats which are arranged to be launched fully loaded from the stowed position, the maximum heeling moment during launching shall be taken;

.2.3 a fully loaded davit-launched liferaft attached to each davit on the side to which the ship has heeled after having sustained damage shall be assumed to be swung out ready for lowering;

.2.4 persons not in the life-saving appliances which are swung out shall not provide either additional heeling or righting moment;

.2.5 life-saving appliances on the side of the ship opposite to the side to which the ship has heeled shall be assumed to be in a stowed position.

.3 Moments due to wind pressure:

.3.1 a wind pressure of 120 N/m^2 to be applied;

.3.2 the area applicable shall be the projected lateral area of the ship above the waterline corresponding to the intact condition;

.3.3 the moment arm shall be the vertical distance from a point at one half of the mean draught corresponding to the intact condition to the centre of gravity of the lateral area.

2.4 In intermediate stages of flooding, the maximum righting lever shall be at least 0.05 m and the range of positive righting levers shall be at least 7°. In all cases, only one breach in the hull and only one free surface need be assumed.

3 For the purpose of making damage stability calculations the volume and surface permeabilities shall be in general as follows:

Spaces	Permeability
Appropriated to cargo, coal or stores	60
Occupied by accommodation	95
Occupied by machinery	85
Intended for liquids	0 or 95*

* Whichever results in the more severe requirements.

*U.S. GOVERNMENT PRINTING OFFICE:1995-600-791/00058